SACRAMENTO PLANT

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INFORMAL PROGRESS LETTER NO. 36

THIRD QUARTER, CY 1965
COVERING THE PERIOD OF
APRIL, MAY AND JUNE 1965 (U)

30 SEPTEMBER 1965

NERVA PROGRAM CONTRACT SNP-1

ROCKET ENGINE OPERATIONS · NUCLEAR

AEROJET
GENERAL TIRE
GENERAL

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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SECTION I

INTRODUCTION

I. INTRODUCTION

This document, the thirty-sixth in a series of informal letters reporting progress of the NERVA engine development program and its associated tasks, is submitted in partial fulfillment of AEC-NASA contract SNP-1. It covers the period of April through June 1965 - the 3rd quarter of Contract Year 1965.

The work accomplished is summarized in Section II of this report, in which the overall program is discussed in Paragraph A, the major end item systems in Paragraph B, and conclusions in Paragraph C. Section III presents a discussion of work performed and is organized on a Task, Subtask, Sub-subtask basis.

Other related quarterly reports issued under separate covers as supplements to this document include the Quality Control and Product Assurance Report and the Subtask Milestone Report.

In order to restrict the amount of material presented to a convenient quantity, the intent is to include in each report only that discussion which is required to provide the reader with a concise summary of the work performed. In general, detailed technical information, lengthy theoretical derivations, and extensive data tabulations have been provided as appropriate in special technical reports. A list of reports published during the period is provided under Subtask 4.3.

This document is the result of combined input from Aerojet-General Corporation and AMF Atomics, a Division of American Machine & Foundry Company, and Westinghouse Astronuclear Laboratory (which submits its reports as a separate document directly to SNPO-C and to the standard distribution established by SNPO-C for progress letter reports). All comments relative to the Westinghouse report should be addressed to REON.

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SECTION II

SUMMARY

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II. SUMMARY

A. OVERALL PROGRAM ACTIVITIES

The summary remarks following, and in Paragraph B, below are intended as a progress picture of the overall program. Work and accomplishments in the sub-tasks essential to the end-items, and to component and system development, are discussed by sub-task in Section III.

In response to the SNPO-C guideline letter of 26 March, studies were conducted with relation to the program for the balance of Contract Years '65, '66, and '67, with resultant program plan submissions and discussions. Adjustments were made in the overall NERVA schedule to reflect the fuel decisions, ETS-1 anticipated availability for XECF and XE-1 testing, and other constraints. The resulting overall program schedule and agency budgets for Contract Years '66 and '67 were submitted in REON Report RN-A-0004, and were intended to be the basis of the definitized Contract Year '66 program cost study initiated during the quarter, and due to SNPO-C in the 4th quarter of Contract Year '65. Additional schedular data were submitted in the Quarterly Subtask Milestone Supplement to Report RN-0560-10-34. The schedule data of Figure 1, NERVA Major Program Milestone Chart, were submitted in RN-A-0004 to partially define the program for Contract Years '66 and '67. As presented in Figure 1, the chart has been upgraded as of 1 July to show latest accomplishments and "expected" dates.

Although the submittal of the above data is largely of a programming and planning nature, it is emphasized in this summary that many extensive meetings, design reviews, and technical studies were conducted to assure that the program would be technically balanced to produce the results desired economically and within allotted schedule.

During the quarter both REON and WANL became involved in a labor strike situation, which caused minor perturbations to schedules in affected areas. At Aerojet during the period of 1 June through 12 July, members of Local 946, International Association of Machinists, were on strike. The impact of this strike was minimized by allocating effort to priority items which influenced immediate schedule requirements. The major portion of the effort was provided by salaried employees.

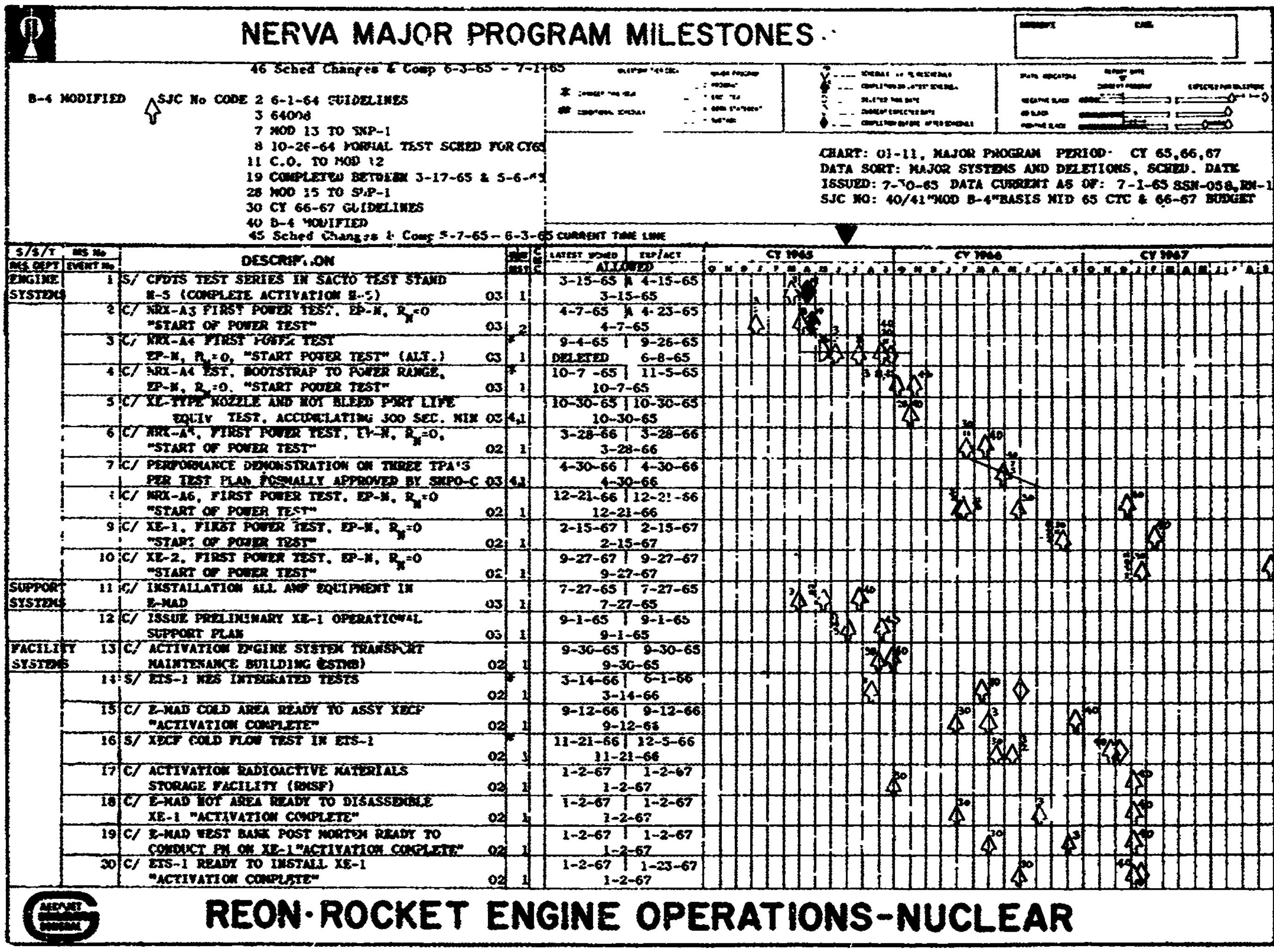

Figure 1

NERVA Major Program Milestones

B. PROGRAM END-ITEMS

1. NRX-A3

The performance of the NRX-A3 reactor development test series was the most significant activity during this quarter. Major objectives of all Experimental Test Plan's (EP's) were met, with the exception that an early termination of full-power test run, EP-IV, occurred on 23 April, because of abnormalities in the facilities systems. The facility turbo-pump shut-down due to spurious noise in the overspeed trip system, while a hydrogen leak in the flow control room was simultaneously building up a concentration which would have probably required an early termination of test. Excessive tie rod temperatures recorded during the resulting abnormal shut-down were traced to a GH_2 flow which was lower than planned. Following examination of available test data, the balance of the EP's were conducted, and over 16-minutes of full-power operation were concluded. Disassembly and post-mortem, partially completed during the quarter, disclosed that (in general) the components of the test assembly were in excellent condition. Data were accumulated that will lead to the reduction of fuel-element corrosion in future assemblies.

2. NRX-EST

Significant progress was made in the Engine System Test Program, NRX-EST (contractually known as NRX-A4-EST). The quarter was entered with unresolved technical and programmatic alternatives which were dependent upon the performance of the NRX-A3 assembly. The generally excellent condition of the NRX-A3 hardware and fuel elements led to the conclusion that the NRX-A4=EST would indeed be run as planned, i.e., primarily as an engine-system test, not devoted exclusively to reactor development test objectives. To quote the SNPO-C letter of 8 June 1965, "-----the primary objective (of NRX-A4-EST) should be achievement of system data under transient conditions and over the entire power range, including full power, with a secondary objective of demonstrating full-power reactor operation up to 30 minutes".

Work progressed on the NRX-A4-EST nuclear and non nuclear components; the majority of the components of the propellant feed system were available or delivered. The EST turbopump (S/N-015) demonstrated its qualifications during tests completed on 6-24-65; nine starts were made, utilizing a total of 22 minutes test time. The EST nozzle, available for delivery, was held pending demonstration tests on a similar nozzle (S/N 021) scheduled for early next quarter. The reactor components, except for fuel clusters, were essentially ready for final assembly. Fuel-element production for NRX-EST was dependent upon solving problems associated with the coating improvements. It was planned that those NRX-A4 fuel elements, which would be in excess of reactor needs, would be used for the XE-1 reactor.

3. NRX-A5

As a result of concentrated efforts involving REON-WANL, and SNPO-C, plans for fuel-element process development were formulated for the NRX-A5 reactor. This reactor will have the primary objective of demonstrating full-power operation in excess of 40 minutes.

4. NRX-A6

It was decided during the period to extend the date previously established for the NRX-A6 reactor test to permit achievement of even greater endurance capability: 40 to 60 minutes at NERVA I power. The decision was also reached that the NRX-A6 reactor design features would involve improvements compatible with the requirements of a larger reactor. Schedules and program plans were generated in support of these decisions.

5. CFDTS

An important engine system design point was demonstrated when the CFDTS test series (conducted from 15 to 20 April) proved the feasibility of boot-strapping the engine system with the energies stored in the engine under ambient conditions. The test program for the second test series was discussed and approved by SNPO-C.

6. XE Engine

XE Engine work was largely in the design and system analysis category. Reprogramming of the XE-1 test to 15 February 1967, was recommended, and commensurate adjustments were made in the design, analysis, and fabrication activities. Complementary plans and efforts were made in the engine design aids program, the MCC-EIV-Engine interface program, and related GSE and engine components program. Engine cool-down studies related to the ETS-1 Test Stand resulted in the elimination of the emergency cool-down system, which had required an 8-in. line external to the engine upper thrust structure, thus considerably simplifying completion of the facility systems aspects of the cool-down requirements.

Work on advanced engines included the study of the conceptual design of various thrust vector control mechanisms. This makes it possible to initiate tradeoff investigations relating such features as clustering, exhaust, circulation, and weight.

Controls analyses indicated that the XE-Engine control system, with gain adjustments, would be satisfactory for the larger engine. A key investigation was initiated to determine from analysis and test the optimum hydrodynamic and cavitation performance of a single turbopump assembly with minimum weight.

7. Support Systems and Programs

Support system work included such items as; completion of the Sacramento test effort on the E-MAD, the overhead positioning systems, and the floating head systems, and delivery of these items to NRDS; the delivery of the OPS mast, trolley, and the inching and leveling frame, to NRDS; the completion of assembly and installation, and the initiation of acceptance testing of the Floor Mounted Handling System.

Support equipment for NRX-A4-EST was partially delivered, with the balance of equipment in good shape to meet the need dates.

Work was initiated on the support equipment design for XE-1. Preliminary details were completed at Sacramento on a combined development and test program for the XE-MCC-EIV interface. In support of this, the simulated ETS-1 Engine Stand was completed, and delivered to the Sacramento check-out area.

Programmatic reviews in conjunction with the Contract Year '66 program plan permitted economies in the support equipments required for individual engines and in the Post Operative Cell Material Transfer System (POCMTS) design.

8. E-MAD

Work continued in outfitting and activating systems and equipments in the Engine Maintenance Assembly and Disassembly (E-MAD) Building. The Wall Mounted Handling System (WMHS), the Overhead Positioning System (OPS), and the Floor Mounted Handling System (FMHS) were received and installed, and acceptance tests were initiated on the WMHS and the FMHS. Shielding integrity checks and test reports for Phase II and III were nearly complete.

9. ETS-1

Initiation of Steam Generator tests represented a major accomplishment in the ETS-1 Program Experimental Plan (EP's) I and II were conducted.

Post-test examinations revealed several anomalies in the condition of the hardware. Evidence of hot-gas leakage at the injector-to-chamber seal was noted on Steam Generator Unit 3 (injector S/N 0018). Examination of the injector faces of S/N 0016 and S/N 0019 (a spare) disclosed cracks in the injector face. The unexpected results triggered an extensive investigation as to the cause and search for possible corrective actions.

Other work in the activation and checkout of the ETS-1 Systems included tests on the gaseous and cryogenic systems, and process water systems simulation tests. Extensive efforts were put forth to devise corrective actions as required in areas of system or hardware delivery and/or quality to minimize the effects of difficulties upon the activation schedule.

In the design phase, the ETS-1 Interface system designs were completed, and procurement was initiated. Work on the Test Stand Control System (TSCS) was highlighted by the completion of the final design review with SNPO-C and the initiation of the TSCS and XE-1 breadboards.

10. H-Area, Sacramento

This quarter was most significant for the NERVA Sacramento Test Zone H, since it marked completion of the construction and activation of this major test facility. This major complex comprises stands H-4, H-4A, H-4B, H-5, and H-6, and is capable of conducting such fundamental development tests of engine hardware as chemical combustion tests; liquid-hydrogen turbopump tests with heated hydrogen drive fluid; cold-flow tests of an engine with non-fueled cores; and valve, line, and component development tests.

Position H-5 was activated during the quarter concurrently with the first CFDTS test series; position H-4A and the hot hydrogen heater concurrently with the TPCV hot-gas tests. Test position H-6 first employed hot hydrogen as a turbine drive fluid during March.

The duration of testing turbopump assemblies was limited by a downgrading of the gaseous hydrogen high-pressure receivers to 3500-psi because of problems possibly associated with operating at the planned 5000-psi rating. It is planned to augment the GH_2 receivers by relocating 3 high-pressure receivers to Test Zone H from Test Zone E.

C. CONCLUSIONS

The NRX-A3 performance and hardware durability was considered excellent. Data obtained indicate that the NERVA Program must continue to devote effort to improving the corrosion resistance of the reactor to attain the desired operating life objective of 40 to 60 minutes.

It was demonstrated, as a result of the CFDTS tests, that the engine system can boot-strap with the energy stored in the engine at ambient conditions.

It was concluded that reprogramming of the reactor and engine programs was necessary to bring into balance priority development tasks, expected facility availability, and certain funding constraints. The recommended actions are under consideration by SNPO-C.

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SECTION III
TECHNICAL DISCUSSION
TASK 1

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1.1 ENGINE SYSTEM

1.1.0 ENGINE SYSTEM INTEGRATION, DESIGN AND DOCUMENTATION

A. XE-1 ENGINE DESIGN

Fluid lines were redesigned to increase reliability by reducing the number of joints and bellows. Modifications to the shield design to accommodate the required larger penetrations and some relocations were about 50% complete.

Design concepts for the pneumatic supply, engine electrical, and emergency cool-down systems, and for brackets and support were revised to be consistent with the elimination of the remote component reassembly capability. Design studies and system analyses of the cool-down requirements were completed, and recommendations were made that no further effort be expended on an emergency cool-down mode requiring an 8-inch line external to the engine upper thrust structure. This mode provided for immediate introduction of ambient helium into the dome of the pressure vessel on receipt of a malfunction signal.

B. DRAWINGS AND DOCUMENTATION

Layout drawings for the experimental Engine (XE-1) were revised to reflect recent line size and location changes.

The XE-EST-1 Interface Control Drawing was upgraded and revised to reflect latest engineering design changes which included changes in location for the pneumatic and propellant lines, and the substitution of the flight type TSOV as a valve at the fixed interface.

The preliminary design layout on the XE-1 was completed for the nuclear/non-nuclear interface control drawings. Design reviews were conducted with WANL participation.

Revisions to the XE-1 flow schematic were studied and will be included in the revised Engine Design Specification to be issued as AGC 90016A.

The basic and assembly parts lists are being maintained current, and are included in assembly and disassembly sequences.

The following NERVA Design Criteria were revised or prepared and issued during this quarter:

NDC-107	Shield Assembly, External, NERVA XE-1 Engine
NDC-110	Line Assembly, Pump Suction, for the XE-1 Engine
NDC-114	Harness, Electrical, for the XE-1 Engine
NDC-115	Turbine Exhaust System for the XE-1 Engine
NDC-116	Pressure Vessel Assembly for the XE-1 Engine
NDC-123	XE-1 Engine Components, General Criteria for XE-1 Engine

C. XE-1 ENGINE ASSEMBLY/DISASSEMBLY AND CHECKOUT

The previously reported assembly and checkout procedures were revised to reflect current modifications to engine design concept.

The Preliminary Post-Operative Disassembly Sequence and a flow chart were prepared, covering the step-by-step disassembly operations from removal of the engine from the test stand after firing to the point where the engine was completely disassembled.

A preliminary rough detail checkout plan has been prepared and maintained.

1.1.2 COLD FLOW DEVELOPMENT TEST SYSTEM (CFDTS)

The revised CFDTS Test Specification, REON Report RN-S-0191, was issued during the second quarter.

Test planning for the XECF program was continued. The first draft of the Test Plan will be issued during the next quarter.

The preliminary design freeze of the X-Engine has been delayed until October 1965. XECF-1A activity is being conducted concurrently with the XE design effort.

The CFDTS Series I Data Summary Report, RN-TM-0196, was issued 6 May 1965. Copies of the data printout and CalComp plots were distributed.

Fabrication of all unique hardware was completed during the second quarter. In addition, a new turbine exhaust manifold system was 95% fabricated during the third quarter. This manifold is to mate with the improved NRX/EST-type TPA to be supplied for use in the CFDTS engine.

Following completion of the installation of the engine in the H-5 test stand, the instrumentation installation, leak checking, and the instrumentation and control systems checkouts on 14 April, the first series of the CFDTS test program was conducted between 15 and 20 April. The series was considered particularly successful since it proved the possibility of boot-strapping with energy stored in the engine at ambient conditions.

Six tests were performed, including wet and dry system chill-down tests and four wet-pump boot-strap start-ups of the system with propellant supply tank pressures of 90, 70, 60, and 50 psia. All tests were run at approximately 14-psia back pressure in the nozzle and turbine ejectors, and at turbine speeds during the boot-straps of 5932, 5260, 4219, and 2190 rpm.

A photograph of the CFDTS after a test run is shown in Figure 2. A heavy coating of frost is clearly shown over the pressure vessel.

Figure 2

The CFDTS after a Test Run

1.1.3 ENGINE EXTERNAL SHIELD DESIGN AND DEVELOPMENT

The layout of the shield revised to accommodate fluid line revisions was continued during this report period. Detail and assembly drawings are being revised.

Modifications were made to the shield design during this period to facilitate assembly and disassembly procedures and to simplify fluid line design. The primary change was the increase of the size of the shield penetration.

1.1.4 TEST CELL A SYSTEMS TEST DESIGN AND DEVELOPMENT

A. NRX/EST DESIGN

Because of the changes to the engine system, resulting from the redesigned TPA, it was necessary to hold a second NRX/EST design review on 14 June. Final redesign was completed during this report period.

Engineering liaison was conducted with WANL/ACFI this report period. All changes have been brought to the attention of WANL/ACFI on a current basis, and interfaces have been identified to reflect present NRX/EST design configuration.

B. DRAWINGS AND DOCUMENTATION

The NRX/EST Engine Assembly drawing was completed and released on 30 June. Thirteen sheets of the NRX/EST Engine Assembly Interface Control drawing have been jointly approved for release by REON and WANL, and all NRX/EST detail component drawings were released during this report period.

The NRX/EST Instrumentation Electrical Schematic Diagram was completed and released on 17 May and Revision "A" was released on 25 June.

The NRX/EST Test Plan was completed and issued in January and the Test Specification was approved and issued on 22 June. Both documents, and the NRX/EST Program Plan include provisions for converting from an NRX/EST test to a reactor test.

NTO Procedure NRX/EST-P2, Non-Nuclear Hardware Receiving Inspection, was approved on 22 June, and NRX/EST-P3, Engine System Assembly and Checkout (Mechanical), was approved on 23 June.

The Test Specification and Procedures Review Board (TS and PRB) convened at NRDS on 8 June and is actively in operation.

Nuclear heating rates and thermal calculations were completed on engine components in the region of the redesigned WANL privy roof mounted shield (PRMS), and were redone for the direct component shield for the redesigned PRMS and its support.

REON Report RN-TM-0219, NRX/EST Redesigned Turbine Inlet Line, was completed, including structural, nuclear, and thermal analyses.

All major malfunctions identified in the Modes-of-Failure Analysis were investigated by using the analog and digital analytical models.

The NRX/EST Shield Assembly - Radiation (REON 1013810-19E) was delivered to NRDS on 14 June 1965 and filled with steel balls on 18 June 1965.

1.1.5 ENGINE DESIGN AND ASSEMBLY AIDS

Drawings of the TSA/XE-1 design-aid final assembly and all previously unreleased details and the Upper Thrust Structure (UTS) design aid final assembly were released in April 1965.

During the report period, changes have been made to the design reflecting component test results and to facilitate fabrication. Fabrication and assembly of the UTS portion of the UTS Design Aid was completed June 28. Fabrication of the TSA Design Aid continued in this report period.

1.1.7 ENGINE ADAPTER AND GAGES

The preliminary test plan was completed for the first phase of testing, and will be finalized during the next report period. The design criteria for the test stand adapter have been revised and reviewed.

Design of the ETS-1 Thrust Ring Engine Adapter Interface Template was coordinated and completed.

A complete complement of present candidate electrical, fluid, and structural remote connectors have been selected and incorporated into the design aid assemblies. Procurement and fabrication of these connectors was authorized on 2 April for the TSA design aid, and on April 15 for the UTS design aid. Testing of the electrical connectors was completed on June 30 and a final report is being prepared. Preparations for conducting the tests on the fluid and structural connectors have been completed, and testing will be conducted during the next report period.

Fabrication was completed for two each of the following match-plates, and delivery was completed in accordance with estimated schedules:

MDF 605472	TSA-UTS (two sets)
MDF 605475	UTS/External Shield/LTS

1.2 PROPELLANT FEED SYSTEM (PFS)

A major effort during this period was directed toward the evaluation and qualification of NRX/EST hardware. Significant accomplishments were:

Seals, couplings, and propellant inlet line hardware required for NRX/EST were delivered

Of the 20 valves required for NRX/EST, 16 were acceptance tested and delivered.

Development tests were conducted on TPA, S/N 0008, accumulating 5 starts and 6 minutes at or near NRX/EST maximum power conditions.

Nine tests were successfully conducted with TPA S/N 0014, accumulating 29 minutes of hot-gas-drive time, including 22 minutes at or near NRX/EST maximum power conditions. Acceptable EST and work statement TPA performance was demonstrated.

1.2.1 LINES AND DISCONNECTS

Fabrication of the EST inlet line and associated spool pieces was completed, and the units were delivered for use.

New turbine exhaust lines for NRX/EST were designed to be compatible with the new turbine exhaust collector, and their fabrication was redirected to also be compatible with the new collector. Completion of the new lines is expected in July. Hydrotest tooling for the new turbine exhaust lines is being fabricated.

All seals and couplings required for the NRX/EST Propellant Feed System were delivered. Approximately 400 seals and 125 disconnects were procured for the NRX/EST.

1.2.2 VALVES

A. H-6 TURBOPUMP OVERSPEED TRIP (OST) VALVE (EMERGENCY SHUT-OFF)

TPCV Assembly, S/N 0012, P/N 278100-59, was delivered to the H-6 Turbopump Test Facility in March. This "On-Off" valve served as a redundant emergency shutoff of turbine drive gas and was powered by a pneumatic piston-type actuator. Actuation of the valve was accomplished by pilot valves operating at 500-psig of GN_2 pressure, through 3/4-in. actuation ports to the TPCV actuator. Elapsed time to open or close this actuator and valve combination under ambient conditions was 50 milliseconds.

This TPCV successfully operated as an "On-Off" valve on Turbopump Test Series 1.2-13-NNP, during which time the valve accumulated a total of 15.3 minutes of operating time, during 5 hot-gas-drive turbopump tests. Operating conditions required a gas flow through the TPCV at a temperature of 1100 to 1200°R, and a valve inlet pressure of approximately 500 psig. The valve was programmed closed at the termination of each test run. Inlet pressure at the time of closure approximated engine system operating pressure. Installation of the unit is shown by Figure 3.

Following this Test Series, these test effects were noted on the TPCV:

Evidence of loading without damage on the valve shaft roller bearings.

Yielding of the valve disc-to-actuator shaft connecting pin, which is attributed to off-design operating condition of this valve application (response time of 50 milliseconds results in excessive torsional forces when the valve disc is abruptly decelerated at the end of the actuator piston stroke.

No other problems were noted on this valve. The unit was reassembled using the same parts (except for a new connecting pin) and subjected to 10 additional minutes of heated H_2 flow on turbopump tests 1.2-15-NNP-001

Figure 3

Overspeed Trip Valve
Installed in H-6 Test Facility

and 002. Valve inlet conditions were approximately 400-psig inlet pressure at a gas temperature of approximately 1200°R. Following run 002, it was noted that the connecting pin from valve disc to actuator had again yielded. To prevent a turbopump test delay, the TPCV was replaced with TPCV S/N 013 for Test Series 1.2-15-NNP-003 through 009.

The total accumulated operating time with TPCV S/N 012 was 25.3 minutes without any failures at design operating conditions. Valve S/N 013 has been subjected to 17 minutes accumulated operating time, during which the valve inlet conditions were approximately 420-psig inlet pressure and 1200°R inlet temperature. The valve has been cycled closed seven times, with the inlet pressure near the design operating pressure.

B. H-6 TURBOPUMP TEST TURBINE POWER CONTROL VALVE (TPCV)

TPCV S/N 013 was assembled and mated to a servo controlled hydraulic actuator, and used for turbine power control during turbopump operation. It was used in lieu of a facility pressure control valve used during the previous turbopump tests, for turbopump tests 1.2-13-NNP-010, -011, and -012, (reported last quarter) and during tests 1.2-13-NNP-013 through -016.

The TPCV operated as a control valve for a total accumulated duration of 7.9 minutes at nominal inlet conditions of 450-psia pressure and 1100°R temperature. The valve functioned in a satisfactory manner; however, gate travel to positions less than 10° from the fully depressed seal ring position was not achieved. Full-pressure shut-off was essentially achieved at positions below 15° from full ring depression.

Post-test disassembly revealed that the actuation and axle shaft roller bearings failed during the test series. An investigation was conducted, and the failures were attributed to excessive flange loading beyond design limits. This loading was imposed in the valve body by thermal expansion and distortion of the facility plumbing, dead-weight flange and line loads of the test set-up plumbing, and differential pressures. The investigation is reported in REON Report RN-TM-0226.

Subsequently, 4 valve tests (1.2-13-NNV-001 through 004, simulating NRX/EST engine plumbing with the TPCV as the test specimen and another TPCV as the bypass valve in the first 3 tests) did not produce bearing failures.

C. DISCHARGE SHUT-OFF VALVE

Acceptance testing of the discharge shut-off valve (Rocketdyne OBV 86, P/N 99-405384, S/N 2527423) for NRX/EST was completed at both ambient and cryogenic temperatures (see Figure 4).

The valve body and actuator were proof tested at ambient temperature, and leakage was measured with GN_2. Butterfly disc seal leakage was 16.6 scc/sec at a differential pressure of 30 psi, and the shaft seal leakage was 26.8 scc/sec with 780 psig in the valve, (both as compared with criteria of 14 scc/sec).

D. DISCHARGE CHECK VALVE (DCKV)

The flapper damper installed in the DCKV, P/N 285994, S/N 003, (discussed in the previous quarterly report) was modified to provide a positive lock on the assembly. This was accomplished by match drilling the rod and the screw with the screw properly adjusted, inserting an Inconel X pin into the hole, and staking the hole. Ambient and cryogenic acceptance testing of the DCKV for NRX/EST was completed. The valve was subjected to proof and leak testing at ambient temperature. The valve showed no bubble external leakage and an internal leak rate of less than 0.05 scc/sec using 1000-psig GH_e at the discharge port. The valve was tested at LH_2 temperature to determine leakage rates and unseat and reseat pressures (1.0 psi differential*). The external joint was bubble tight at 500 psi using GH_e. Internal leakage was 108 scc/sec of H_e with 1000 psig at the discharge port (as compared to criteria of 25 scc/sec maximum leakage). The valve operation requirements as related to the system were reviewed and it was determined that the valve is acceptable for NRX/EST usage.

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* unseating pressure

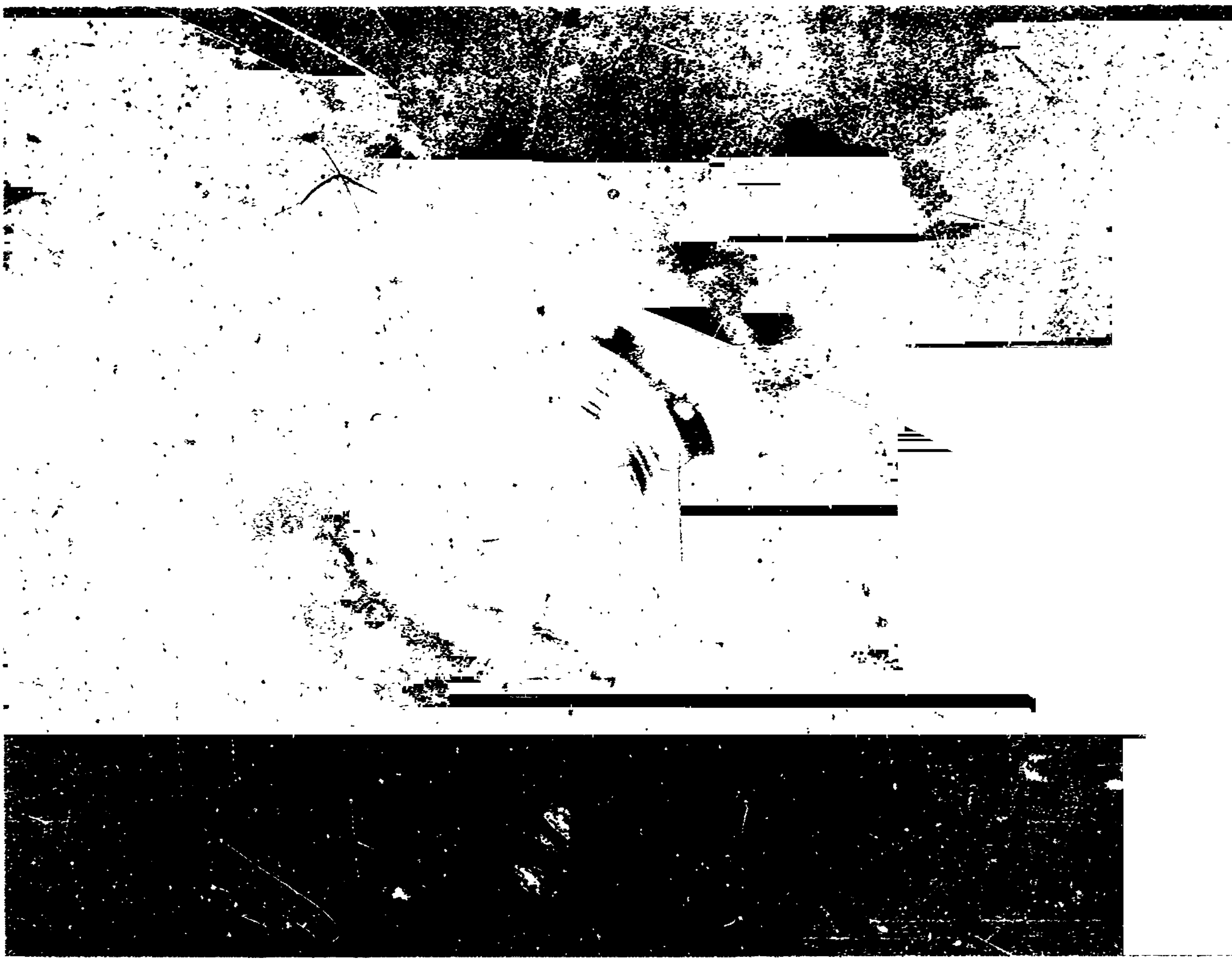


Figure 4

Discharge Shut-off Valve

Rocketdyne OBV 86

E. PROPELLANT SHUT-OFF VALVE (PSOV)

NRX/EST acceptance tests were successfully conducted on the PSOV in accordance with the test plan. All the acceptance criteria stated for the tests were met.

F. TURBINE POWER CONTROL VALVE (TPCV)

Four hot hydrogen flow tests were conducted on one TPCV assembly at temperatures of approximately 1200°R. The test assembly (P/N 1013762-9, S/N 010) consisted of a valve, torque meter, and servo-controlled hydraulic actuator, as illustrated by the photograph of Figure 5. A second TPCV powered by a Bendix Actuator (P/N 284840-59) was used in the test program as a hot-gas bypass valve; a necessary requirement to provide a method of disposing of the high-temperature supply gas when the test specimen TPCV was closed.

TPCV Test 1.2-13-NNV-001 was completed on 28 April 1965. During the test duration of 270 seconds the TPCV was programmed to cycle open and closed. Actuation torque values in excess of 800 in.-lb were encountered when differential pressure across the butterfly exceeded 400 psi. Attempts to fully close the valve resulted in torque values greater than 1200 in.-lb at valve butterfly disc positions of approximately 18° from the fully depressed seal position, (the valve was fully depressed at 0°). Immediately following the test (which included an inlet pressure of zero, and a valve metal temperature at approximately 700°R) the TPCV S/N 0010 was programmed closed, which again resulted in torque requirements greater than 1200 in.-lb at a butterfly disc position of approximately 18°. Subsequent investigation revealed minor galling of the seal ring on the surface adjacent to the disc groove sidewall.

A third restraining pin was incorporated into the disc and seal ring assembly to further restrict seal ring side motion when the disc is rotating. Test 1.2-13-NNV-002 was conducted 19 May 1965. Test duration was 543 seconds, during which time TPCV S/N 0010 was cycled (full open to full closed).

Figure 5

TFCV Hot-gas Test Assembly

Valve, Torque Meter, and Hydraulic Actuator

Post-test inspection of this TPCV, again revealed excessive axial loading of the disc seal rings, which caused galling. Valve build-up S/N 003 included seal rings with rounded edges and with M_oS_2 applied. M_oS_2 was also applied to the disc groove and to the roller bearing elements.

The third test (1.2-13-NNV-003) of the TPCV development program was completed on 3 June. Test duration was 350 seconds, during which time the TPCV was cycled 10 times between disc positions of fully closed and fully open. The required torque to close the valve was a maximum of 400 in.-lb at a disc position of 8°; the corresponding differential pressure was 300 psi, and the valve inlet pressure, approximately 300 psig.

Test run 004 was conducted 4 June for a duration of 387 seconds. The TPCV S/N 0010 was cycled once between fully open and fully closed; thereafter cycling was limited to disc positions of 60° to fully closed. A total of 15 cycles between 60° and 0° was accomplished.

Fabrication of the ten TPCV's reported last quarter was completed, and TPCV's S/N 0012 and 0013 were reassembled to support TPA testing.

G. DILUENT CONTROL VALVE (DCV)

A liquid hydrogen flow and functional test (1.2-12-NNV-011) was successfully conducted with a TPCV used as a Diluent Control Valve. An obsolete "B" series Bendix Actuator was used to position the valve during this test. An ambient pretest actuator control system functional check was conducted with no flow or pressure. The butterfly disc was rotated from 30 to 55° for 21 oscillations (30° to 55° = 1 oscillation, 0° = closed). Test conditions, approximating engine conditions, were 650-psig valve inlet pressure with approximately 2.5 lb./sec of 35°R hydrogen flow. The value butterfly disc was positioned at 10, 20, 25, 30, 40, 50 and 60 degrees, and the pressure drop across the valve disc measured at each increment to obtain data of flow factor as a function of disc position.

The valve disc was subjected to 10 oscillations (30° through 55° = 1 oscillation) simulating NRX/EST functional performance. The test was concluded after 15 cycles (valve disc closed-to-open = 1 cycle) to establish open-close capability in LH_2 at 650-psig inlet pressure. Post-test disassembly revealed the valve components to be in excellent condition.

This test, the DCV LN_2 functional test, and the DCV design report, reported in REON Reports RN-TM-0210, 0137, and 0141, respectively, complete the development tests and analyses required to qualify the valve for DCV service with the NRX/EST.

The DCV for NRX/EST was assembled, and ambient acceptance tests were completed.

Note - Items H, J, K, L, M, N, P, following are added scope for NRX/EST.

H. TURBINE BLOCK VALVE

Acceptance tests on a TPCV to be used as the NRX/EST Turbine Block Valve (TBV) were completed on 28 June. Included in the acceptance testing was proof, leak, and functional testing under ambient conditions. Subsequently, a heated hydrogen flow test of the valve was conducted at 1100°R, in which the valve was cycled open and closed three times. Inlet pressure to the valve was maintained at 525 psig. The "fail open" feature of the valve design was demonstrated by venting the actuation line with the valve initially open.

J. HOT BLEED VENT VALVE

A TPCV to be used as the NRX/EST Hot Bleed Vent Valve was subjected to proof, leak, and functional tests with successful results. Final acceptance of the valve is pending the heated hydrogen flow test, which will be conducted in conjunction with the TPCV acceptance test.

K. SOLENOID VALVES

A test plan was completed for a Marrota 3-way solenoid valve and the Barksdale 4-way solenoid valve. These valves are utilized on the FCB (OBV-86) redundant actuation system and the TFV and HFVV. The

Marotta 3-way solenoid valves and the Barksdale 4-way solenoid valve were successfully acceptance tested. Testing included proof, leak, functional, and dielectric strength testing.

L. VENT VALVE (VV)

Development tests were completed on the Flomatics 2-in. vent valve. Acceptance tests of the 2, 2-in. vent valves for NRX/EST were successfully completed in accordance with the test plan.

M. PURGE VALVE (PV)

The specification control drawing for the 1-in. purge valve was completed and released; the valve is supplied by Flomatics Inc., and is of the Y-globe configuration. Development tests were completed.

Disassembly and inspection of the valve after development testing revealed a loose seal retainer plate cap screw which holds the main poppet seal in place. The cause of the loose cap screw was found to be an improperly installed locking Helicoil which was not engaging the cap screw. A new locking Helicoil was inserted into the poppet, and a new cap screw engaged and checked for tightness. This same corrective action was then applied to the 2-in. vent valves which are similar in design to the 1-in. purge valve.

Acceptance tests of the 1" PV-1 for NRX/EST were completed, and met the acceptance criteria of the test plan.

N. CRYOGENIC TEMPERATURE PURGE CHECK VALVE

Development tests were completed on the Circle Seal 3/8" Check Valve. Acceptance tests of the two cryogenic check valves were completed. Excessive internal leakage rate of one valve during test 5 was attributed to the valve not being in the check position when chilled to LH_2 temperature, as it would be in the EST engine system. The other valve, was chilled in the check position and indicated no leakage for this test. These valves will be acceptable for NRX/EST usage. An additional 7-3/8" cryogenic check valves were procured from Circle Seal Inc., for use as spares for NRX/EST, and for future uses on the XE Engine.

P. ELEVATED TEMPERATURE PURGE CHECK VALVE

The fabrication drawings and top assembly (REON P/N 1114730) were completed, and the valve was fabricated and successfully acceptance tested for NRX/EST. Initial development testing of this 3/8" check valve was conducted with a prototype unit utilizing a Type 347 stainless steel body and piston.

Ambient temperature tests produced good results, but hot-gas tests with 800°F gas flowing through the valve (a much more severe condition than the valve will experience in service) produced occasional sticking between the piston and body. The clearance between the piston and body was increased from .002 to .005 by reducing the diameter of the piston. No sticking of the piston was experienced in further ambient or hot gas testing.

The piston material was upgraded from Type 347 to Inconel X for the NRX/EST Valves (P/N 1114730-10). No problems were experienced with the Type 347 pistons, but the harder material will produce longer cycling life and be more resistant to abrasion from dirt particles.

Acceptance tests of the 2 valves to be used in NRX/EST were successfully completed.

1.2.3 TURBOPUMP ASSEMBLY (TPA)

A. GENERAL

The testing of turbopump S/N 008 was continued. The assembly of S/N 014 turbopump was completed and testing was initiated. Mark III Mod 4 pump water test documentation of performance was continued. Numerous materials tests were performed.

B. S/N 008

Turbopump S/N 008 completed 5 hot-gas starts and approximately 6-1/2 minutes of operation at or near NRX/EST conditions.

During this report period Tests 1.2-13-NNP-014, -015, and -016 were initiated on TPA S/N 008, P/N 287900-219, to evaluate turbopump performance at or near NRX/EST conditions and to further evaluate endurance. Test -015 was the fifth and last hot-gas test on this TPA, while Test 016 was a GH_2 test for performance documentation for cold and hot gas comparison.

Post-test hardware investigation of this turbopump revealed that the A-286 first-stage turbine rotor had a circumferential crack approximately 3/8-in. long in the disc portion near the rotor hub fillet.

The required turbine inlet pressure to drive Turbopump S/N 008 was considerably below that to be available in the NRX/EST. For a pump ΔP of 951 psi and a pump weight flow of 77 lb/sec, the required P_{TTI} was 550 psia.

C. S/N 014

Turbopump S/N 014, P/N 708800-59, was assembled. This turbopump completed 9 hot-gas starts and 29 minutes of hot-gas drive operation, of which 22 minutes were at or near NRX/EST conditions.

This turbopump was initially tested on 30 April. Post-test performance analysis revealed that performance was significantly improved over the S/N 008 turbopump.

Performance improvement resulted from:

- Increased turbine inlet-manifold inlet area.
- Decreased bearing-coolant labyrinth gap.
- Decreased impeller-angle vane clearance.
- Reduced flow discontinuities in first-stage turbine nozzle.
- Sealed instrumentation holes in turbine housing.
- Reduced second-stage nozzle labyrinth clearance.
- Increased area turbine exhaust manifold (not used initially; but used during latest tests).

The turbopump met all requirements for the NRX/EST vehicle. A summary of Turbopump testing conducted in this period is reported in Table 1.

D. STATIC SEAL LEAKAGE

Turbopump external static seal evaluation continued. Close attention was paid to static seal performance during, as well as after turbopump tests. After Test -014, fire-leak check did not indicate any leakage; however, motion pictures recorded during the test indicated that a substantial leak occurred between the pump support flange and the pump housing.

Following this test, (run without repairs) TPA S/N 008 was disassembled for hardware evaluation. All parts were in good condition except for the crack found in the first stage turbine disc.

Test -015 was conducted without repairs. As with Test -014, leakage was evident on film, but the post-fire leak check revealed no leakage.

After the bolt torques of the flanges on both sides of the pump housing were increased to 300 in-lb, leakage was not evident during the 29 minutes of hot-gas-drive testing the S/N 014 turbopump.

Test	Run Date	P/N	S/N	Cold Gas (1)	Hot Gas	Above 15,000 rpm	At or Near EST Cond. (2)	Max Speed (rpm)	Max P_{TPD} (psia)	Max ΔP (psi)	Max $\dot{W}$ Pump (lb/sec)	Range of Q/N (gal/rev)	Range of NPSP (psi)	Max P_{TTI} (psia)	Max T_{TI} (°R)
1.2-13-NMP-014	4-04-65			0	184	143	0	22,700	1014	964	51.5	.28-.30	18-30	472	1224
1.2-13-NMP-015	4-05-65	287900-219	008 BU 4	0	234	153	138	22,300	987	951	76.9	.36-.37	19-29	550	1234
1.2-13-NMP-016	4-06-65			120	0	94	0	22,000	940	904	76.9	.34-.38	18-27	554	622
1.2-15-NMP-001	4-30-65	708800-49		0	280	215	285	22,000	997	949	70.6	.33	24-25	383	1192
1.2-15-NMP-002	5-01-65		014 BU 1	0	269	200	247	22,100	995	952	84.6	.36	23-26	451	1218
1.2-15-NMP-003	6-11-65			0	215	204	137	22,400	1004	965	78.5	.36	16-17	431	1141
1.2-15-NMP-004	6-11-65			0	324	130	187	22,200	999	958	80.6	.35-.36	16-17	424	1277
1.2-15-NMP-005	6-17-65			0	82	29	79	22,000	962	929	76.8	.36	17-18	415	1139
1.2-15-NMP-006	6-17-65	708800-59	014 BU 2	0	147	118	102	21,900	961	928	75.0	.35	15-16	406	1227
1.2-15-NSP-007	6-18-65			0	172	139	122	21,900	961	928	76.6	.36	15-16	415	1237
1.2-15-NMP-008	6-21-65			0	73	41	9	22,700	998	972	76.5	.35	7-8	430	1137
1.2-15-NMP-009	6-22-65			0	186	177	152	22,950	1050	1021	76.2	.34	8-9	437	1233
Total Run Times		TPA S/N 008 (3)		120	418	390	138								
		TPA S/N 014		0	1748	1253	1320								

(1) [illegible] including time on the diluent system.

(2) Minimum conditions are EST conditions less 10% on any one parameter.

(3) Does not include test time prior to test 1.2-13-NMP-014.

EST Conditions:

$\dot{W}_P$ = 77 lb/sec ΔP Pump 880 psia

°R FSP = 4000 based on P and ρ = 4.4 lb/ft3

T_{TI} = 1180 ± 50°R

Table 1

Turbopump Test History

E. TURBINE DISC CRACK

Turbopump S/N 014 accumulated 29 minutes of hot-gas drive time of which 22 minutes were at and above maximum power for (NRX/EST) but the post-test disassembly and hardware investigation of Turbopump S/N 008 showed that its first-stage A-286 rotor, (S/N 274) had a crack approximately 3/8-in. long in the disc near the hub fillet. The required turbine drive pressure was higher in Turbopump S/N 008, and, conversely, the circumferential pressure distribution was improved around the S/N 014 turbine inlet manifold.

Analysis of the cracked rotor was made in this manner:

Visual metallographic inspection and photographic documentation of crack and adjacent areas.

Review of Procurement and Quality Control documentation.

Measurement of applicable dimensional attributes.

Hardness measurements to confirm heat treatment.

Visual inspection of the part revealed a scratch which was coincident with a portion of the crack. The scratch was similar in appearance and orientation, but, more severe than other polishing scratches in the fillet region, both near and removed from the crack. The surface length of the crack was about 0.37-in.-long, and its central portion was located at the base of the upstream fillet and offset from one of the rotor mounting hole locations. The metallographic photograph, Figure 6, illustrates transgranular appearance of this crack.

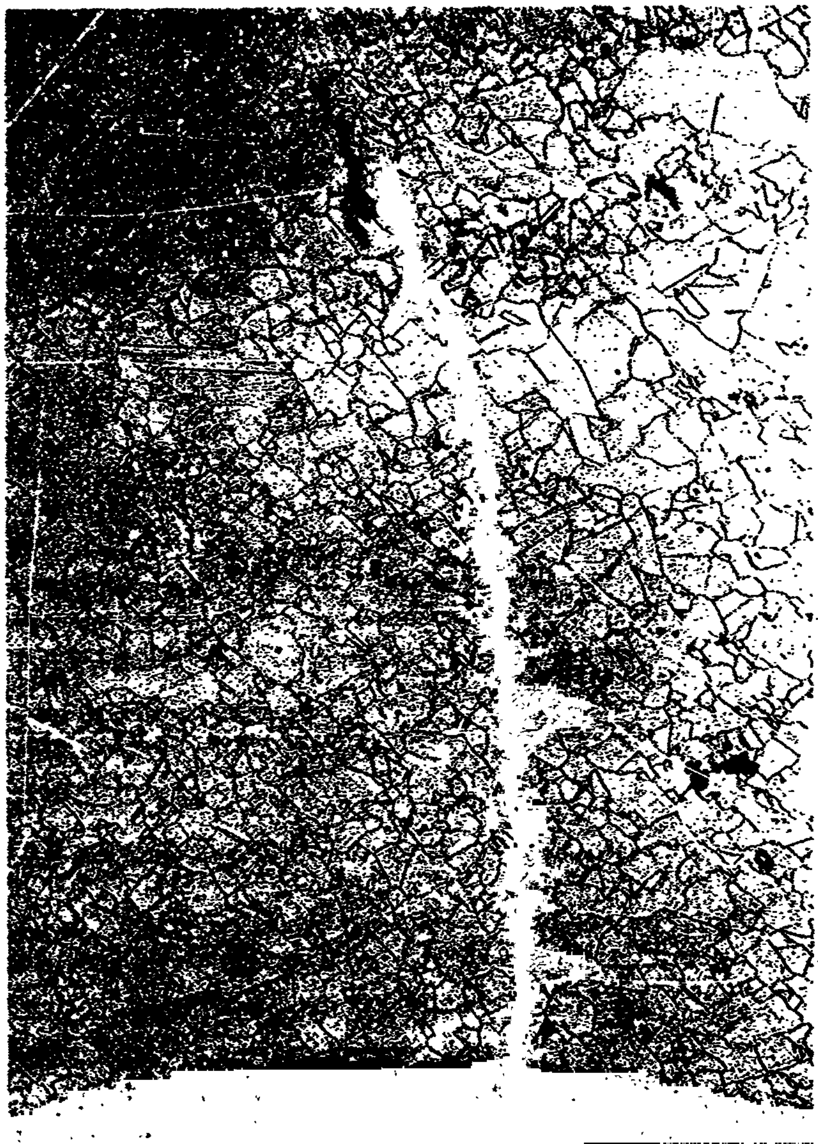


Figure 6

Turbine Disc Crack, Rotor S/N 274

Intergranular Nature at 100X

Etchants: HCl, HNO_3 and Acetic

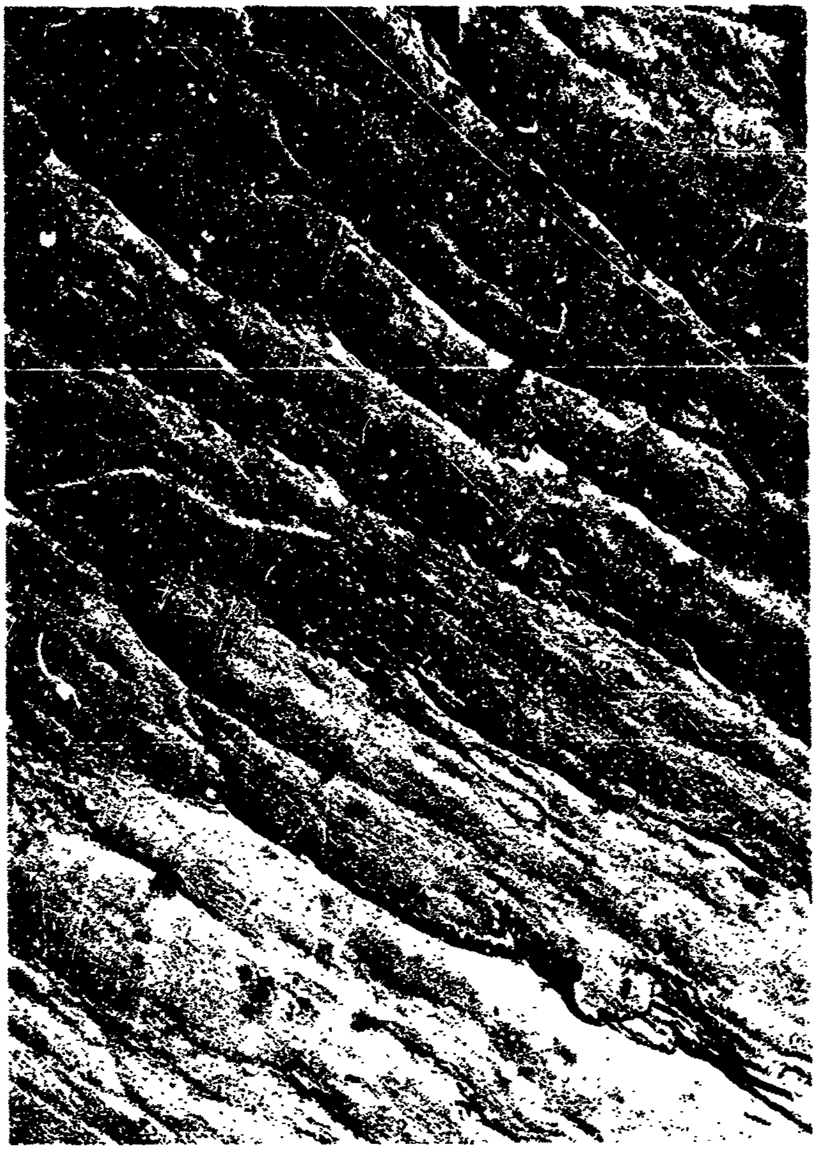
Metallographic examination showed transgranular propagation of the crack. The crack was broken open to enable examination of the fracture surface, which was semi-elliptical and generally flat, indicative of propagation in fatigue. The fracture surface was clean with no scale or discoloration from prior processing. Crack depth was 0.160 inch. Electron micrograph replicas were made from the central portion of crack surface.(See Fig. 1) A rippled texture was revealed by this technique, characteristic of fracture propagation under cyclic loading. The combination of the electron metallography, crack surface appearance, and rotor surface condition led to these conclusions:

> The crack was nucleated by a combination of unfavorable surface conditions including scratches.
>
> The crack was propagated in fatigue.

Material physical properties and turbine operating conditions were utilized in structural analyses of the turbine disc operation. A program was initiated to evaluate the turbine rotor non-destructive inspection techniques and procedures including:

> visual,
>
> ultrasonic inspection (using a turbine rotor as reference),
>
> dye penetrant (Zyglo process),
>
> residual stress check (X-ray defraction method),
>
> Eddy current which may be particularly suitable for grain size checks,
>
> acid etch hub area for grain size.

A technical report was initiated to include the results of all turbine disc analyses and investigations.



Characteristic fatigue striations are spaced at approximately 36 microinches between major peaks.

Figure 7

Turbine Disc Crack, Rotor S/N 274
A-286 Alloy, Electron Fractograph at 12,850 X

F. PERFORMANCE

The turbine efficiency of S/N 006 turbopump was considerably lower than had been predicted. Turbopump S/N 014 was assembled (BU 1) as P/N 708800-49, which included these features for performance improvement:

> Increase of turbine inlet manifold inlet area from 4.3 to 8.3 in^2,
>
> Decrease of bearing coolant labyrinth gap for a flow-rate change from 1.25 to 0.95 lb/sec at a pump ΔP of 900 psi.
>
> Decrease of impeller angle vane clearance from .0375 to .0275.
>
> Reduced flow discontinuities in first-stage nozzle.
>
> Add shim seal to first stage nozzle to prevent leakage around outer periphery.
>
> Improved pump diffuser vane entrance finish.
>
> Sealed instrumentation holes in second stage turbine nozzle housing.

A turbine exhaust collector with increased flow area was installed for test 1.2-15-HNP-002. TPA S/N 014, BU 2 (PN 708800-59) is shown with the new exhaust collector in Figure 8. Corresponding to a pump pressure rise of 1000 psi, a pump flow rate of 75 lb/sec, an NPSP of 10 psi, and a turbine inlet total temperature of 1200°R, the required turbine inlet pressure of this turbopump was 436 psi.

Turbine efficiency test results are shown in Figure (9). The latest revised predicted map was constructed from water test data*. Test data from test series 1.2-15-HNP-001 through -007 on TPA S/N 014 are plotted on the map, and it can be seen that these data agree well with the predictions. It should be noted that the pump performance

---

* and is presented in Figure 10

map was constructed for an NPSP of 20 psia, while the data plotted onto the map are for other NPSP values. Some deviation may therefore be expected between the data and the map.

Pump efficiency and pump head rise are plotted as functions of the flow rate to speed ratio (Q/N) in Figure (11). These data were obtained from the same test series and the same TPA as for the performance map, except that the curves shown as solid lines were obtained from water testing. On Runs -003 through -007, the head rise parameter ($\frac{\Delta H}{N^2}$) for the TPA tests is somewhat lower than in the water test curves. This lower head rise is considered the result of a lower NPSH in Runs -003 through -007 than in Runs -001 and -002. It should also be noted that data for Run -002 may be in error due to faulty instrumentation on the discharge pressure measurement.

The turbine flow parameter, ($\frac{\dot{W}_t \sqrt{T_{TTi}}}{P_{TTi}}$), was measured during turbopump tests to be 0.54 to 0.56 ($\frac{in^2 \sqrt{°R}}{sec}$), which was in agreement with manifold and nozzle air tests. The turbine weight flow measurement orifice size was corrected for test -003. The previous orifice was too large for accurate flow data.

Test 1.2-15-NNP-009 was run to demonstrate work statement conditions, and proved satisfactory in all respects. A maximum ΔP of 1021 psi was attained at a P_{TTi} max of 437 psi, an NPSP $\sim$ g psi, a T_{TTi} max of 1233°R, and $\dot{W}_p$ of 75 lb/sec; had an NPSP of 10 psi and T_{TTi} of 1200°R been attained at exactly the same point in time, the analysis indicates that a P_{TTi} of 436, rather than 440 psia, would have been required.

G. TURBINE-MANIFOLD AND FIRST-STAGE NOZZLE COLD-FLOW TESTS

A series of air flow tests (with 8 setups) were conducted to evaluate the performance of different turbine inlet manifold-first stage nozzle configurations, and a report was prepared on the results. These tests were based on the configuration established and used in the S/N 014 development turbopump, and in NRX/EST turbopump S/N 015.

(Text continued on page 54)

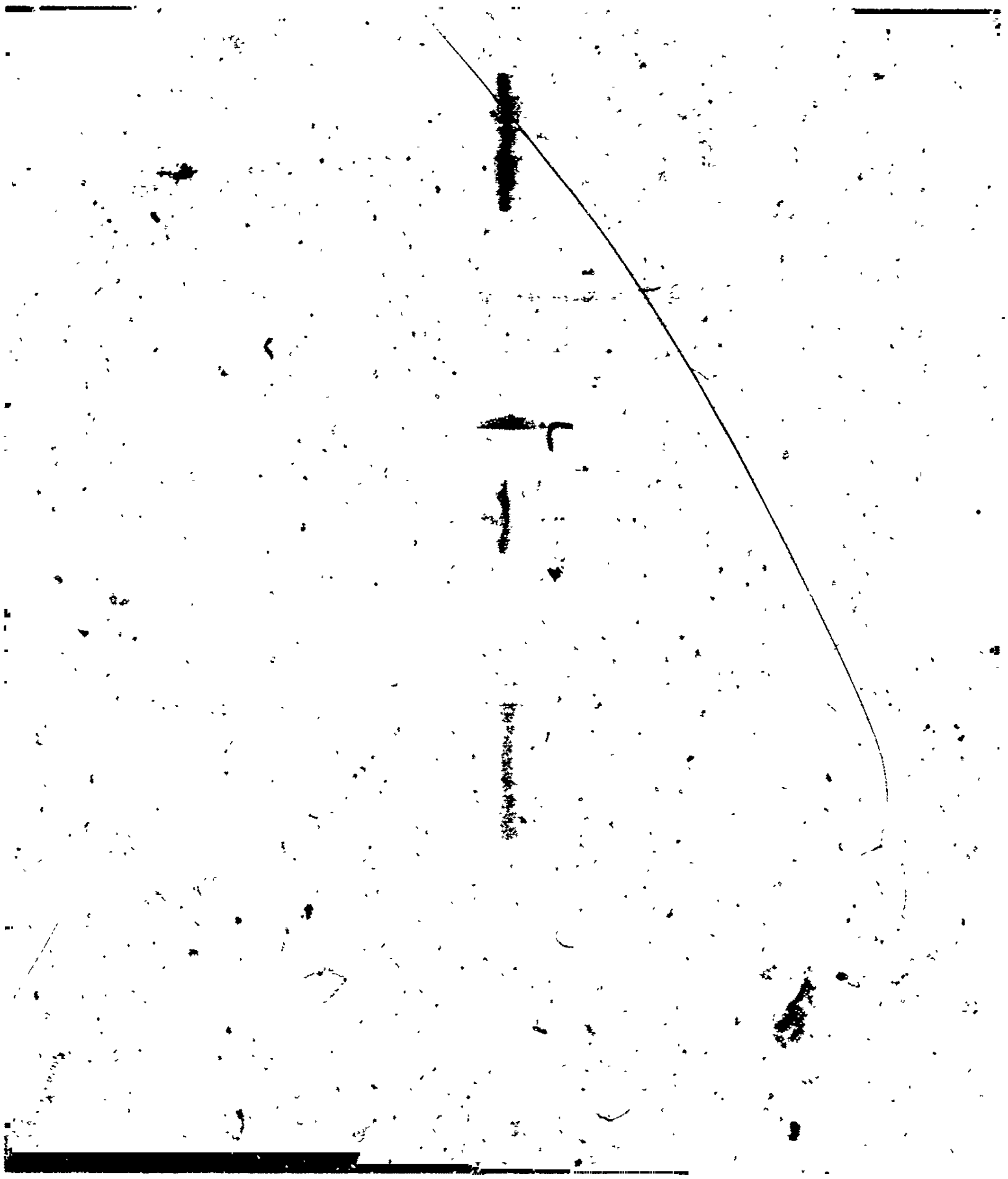
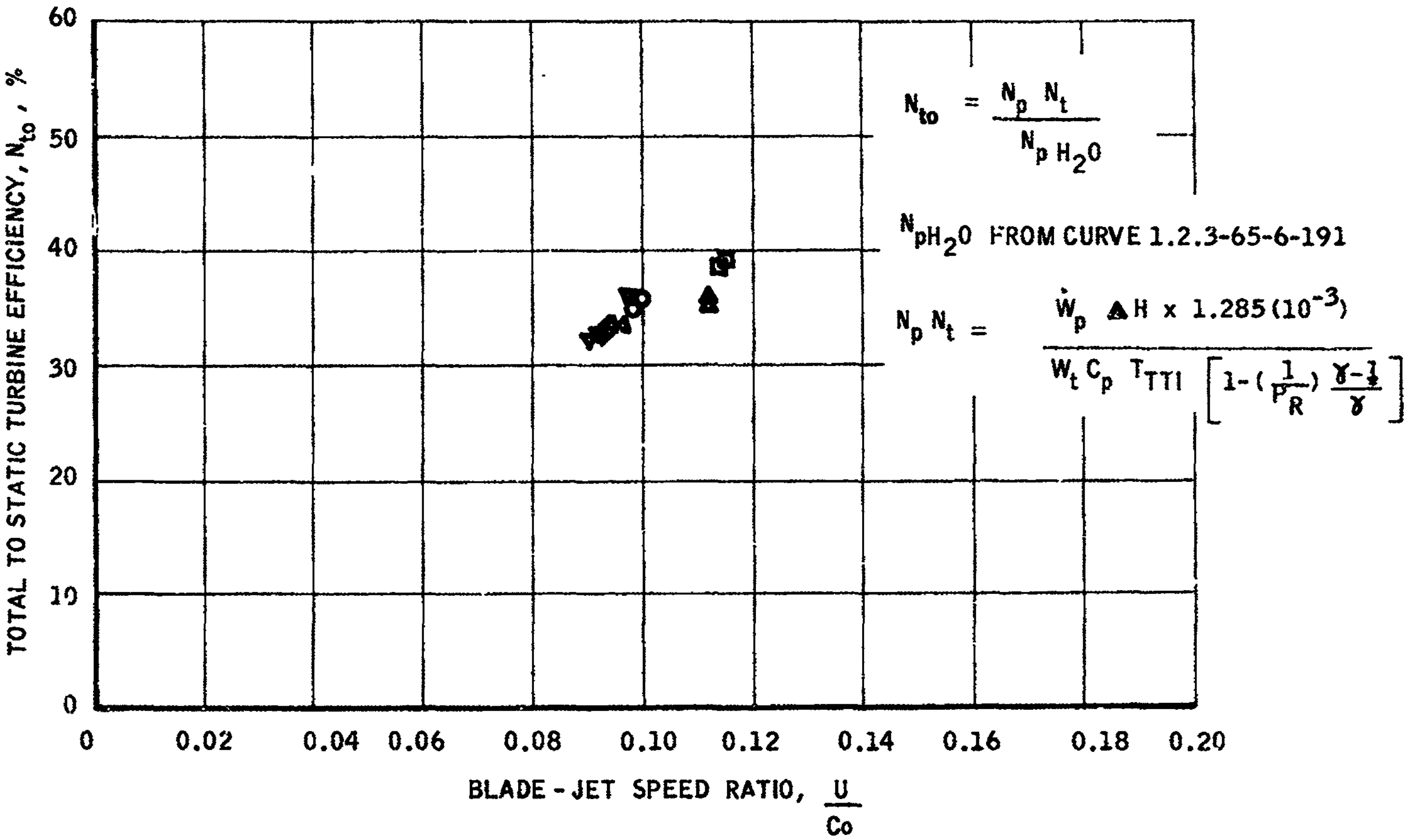


Figure 8

Mk III Mod 4 Turbopump S/N 014
with Exhaust Collector



LEGEND

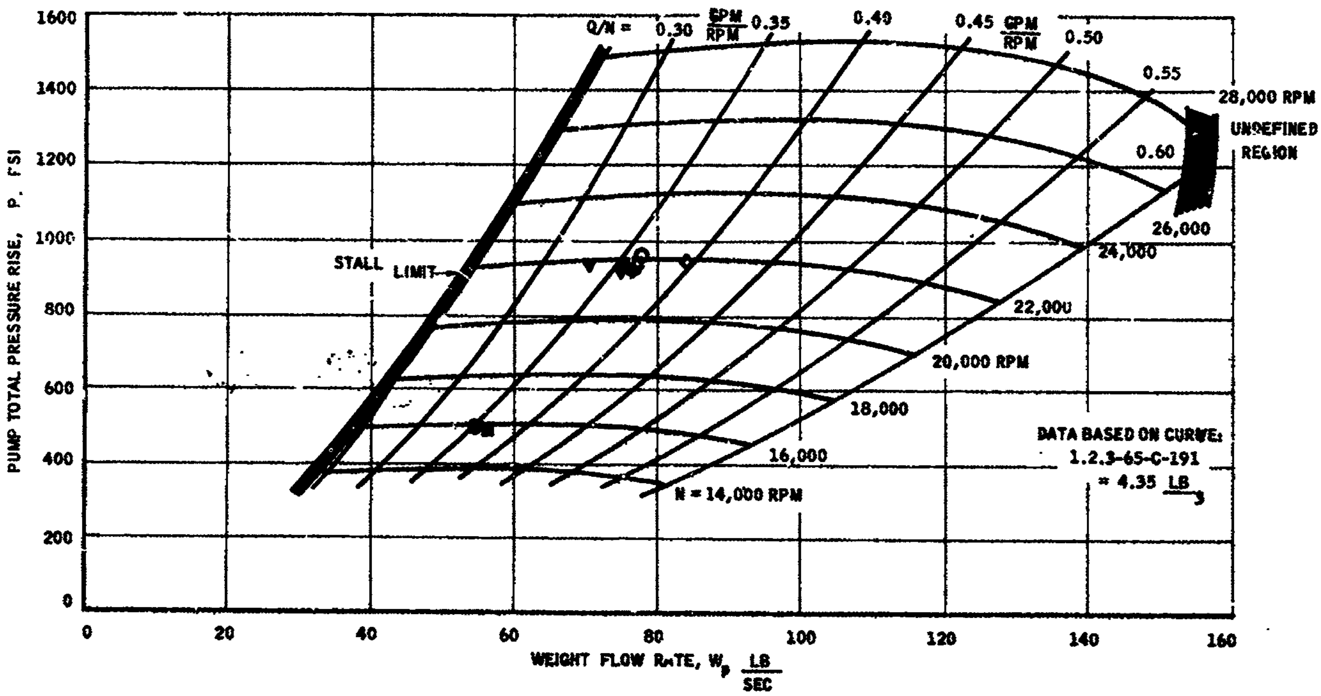
SYMBOL	TEST NO.	Q/N	NPSP	COMMENT
◘	1.2-15-NNP-001	0.375	24.7	
▲	002	0.377	26.2	
○	003	0.357	17.2	NEW EXHAUST COLLECTOR & NEW ORIFICE
▼	004	0.357	15.4	
▶	005	0.356	15.0	
◀	006	0.350	15.1	
◇	007	0.358	16.4	

Figure 9

Mark III Mod 4 Turbine

Revised Static Efficiency vs. Blade-Jet Speed Ratio

$T_{TTI} = 1130 - 1230^{o}R$



LEGEND:

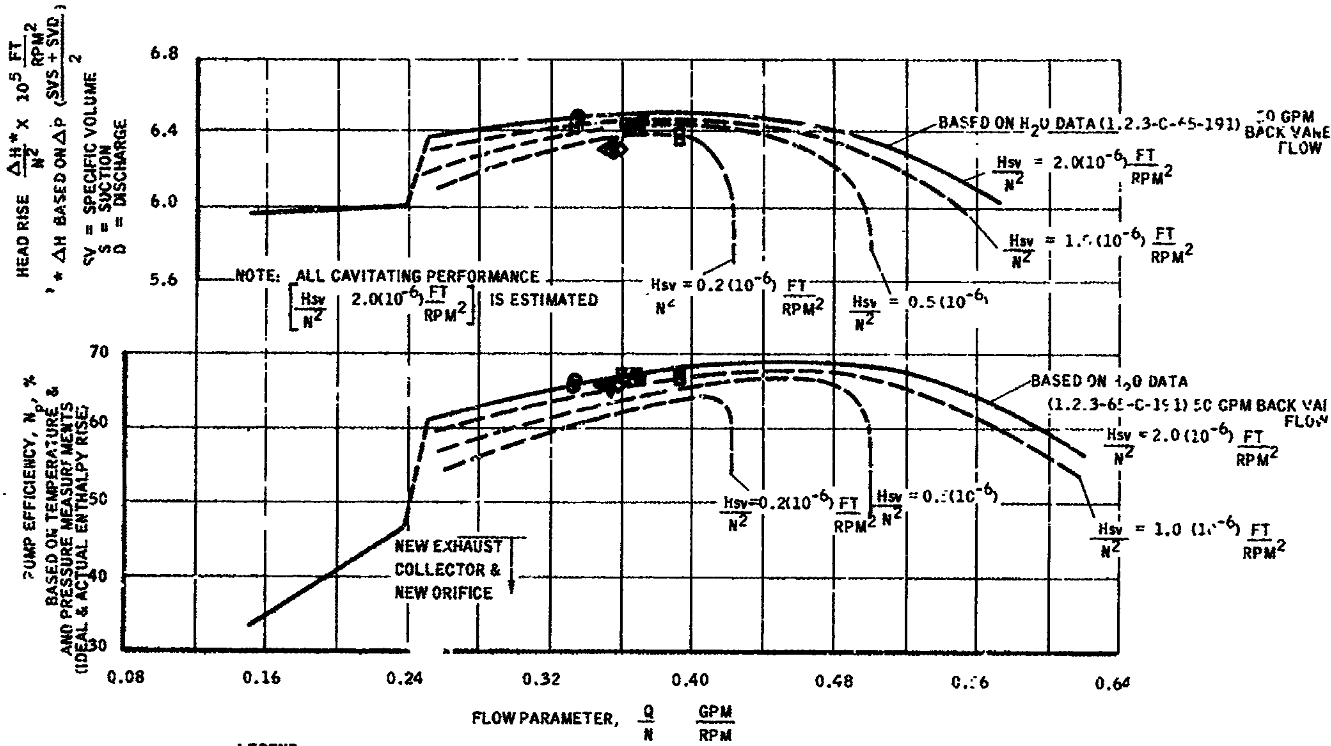
SYMBOL	TEST NO.	SPEED	Q/N	NPSP
▼	1.2-15-NNP-001	21.8K	.333	24.05
◇	1.2-15-NNP-002	21.9K	.291	28.20
○	1.2-15-NNP-003	22.3K	.355	17.03
⊖		15.9K	.349	28.93
⌑	1.2-15-NNP-004	22.0K	.356	15.29
■		15.8K	.362	32.89
▲	1.2-15-NNP-005	22.0K	.357	14.71
◊	1.2-15-NNP-006	21.8K	.351	14.49
◈	1.2-15-NNP-007	21.8K	.358	16.12

Figure 10

Mark III Mod 4 Turbopump

Revised LH_2 Pumping Performance

NPSP = 20 psi



LEGEND COMMENT	$\frac{Hsv}{N^2}$	SYMBOL	TEST NO.	TEST FLUID
	1.71×10^{-6}	○	1.2-15-NNP-001	LH_2
	1.79×10^{-6}	⊡	1.2-15-NNP-002	LH_2
	1.13×10^{-6}	●	1.2-15-NNP-003	LH_2
	1.05×10^{-6}	▼	1.2-15-NNP-004	LH_2
	1.04×10^{-6}	◀	1.2-15-NNP-006	LH_2
	1.13×10^{-6}	◇	1.2-15-NNP-007	LH_2

Figure 11

Mark III Mod 4 Turbopump

LH_2 Pumping Performance

Head Rise and Efficiency vs. Flow Parameters

H. MATERIALS ANALYSES AND TESTS

Two lots of Bergman Manufacturing Co. impeller blank forgings were successfully completed. The first lot included S/Ns 117, 118, and 116; and the second lot included 6 parts shipped to AGC, 5 parts shipped to Paragon, and one qualification forging. The forging process, including upset ratio, upset cycles, and forging temperatures, was established and satisfactorily tested in forging S/N 116. The material was reduced from 13-in.-dia bar to a 9-in.-dia bar (necked), and then upset back to 13-in.-dia. This sequence was performed four times at a forging temperature of 750°F.

The non-directionality of the resultant forging was verified visually and by mechanical tests. The specified properties of 66 ksi ultimate strength, 56 ksi yield strength, and 8% minimum elongation were met in specimens tested by Bergman as well as those tested at Aerojet. The favorable comparison of the tangential and radial properties corroborates the isotropy visually observed.

Tests were conducted to determine the degree of impeller fatigue life improvement that could be expected in shot-peened parts. Four tangential fatigue specimens were machined from an Alcoa impeller forging and shot peened to Almen intensity 0.011 A.

Shot peening increased the failure stress at 10^6 cycles by approximately 30%. It was determined that shot peening of machined impellers in the vane roots and on the base could be accomplished to uniform depth.

Work was initiated to determine to what extent the Mil-A-8625 Type II (sulfuric acid) anodizing process affected the fatigue life of the materials in the impellers as forged. Eight rotating beam fatigue specimen were removed from test section #1 (radial) of the Bergman qualification impeller blank forging S/N 116; this had been previously heat treated by Bergman to the T73 condition. Two fatigue specimens were anodized according to the MIL specification and fatigue tested.

Three non-anodized control specimens were tested to determine effects, if any, of the anodizing process. Results indicate that a loss in endurance of one order of magnitude occurs at a stress level of 30 ksi.

Pump housing casting, S/N 112, was rejected during normal inspection because of a large gas pocket in the volute section. Room temperature and cryogenic tensile tests of the volute section were performed to evaluate the casting technique and the conformance of the part to Aerojet mechanical property requirements. Room temperature and cryogenic properties of the volute were reported in the previous Quarterly Progress Letter. In summary, a mechanical property gradient was noted which was characterized by good properties in the drag area, and poor properties at the parting line and in the cope area. These data are summarized in Table 2, and illustrated in the photos of Figure 12.

Additional testing was subsequently performed to determine the mechanical property variation in the heavy section of the housing inboard of the volute section. Tangential tensile and fatigue specimens were removed and tested at room temperature; results indicated that the tensile data from the heavy section of the casting simulated the strength gradient in the volute section. As expected, rotating beam fatigue results indicated better fatigue resistance of specimens cut from the drag portion of the casting, reflecting the effect of macro-porosity on fatigue life. An apparent allowable of 20,000 psi of complete stress reversal was determined for endurance to 1000,000 cycles.

Comparisons were made of the properties of turbine rotor materials, D-979 and A-286, to illustrate the trade-off of strength for ductility. Table 3, which compares room temperature and cryogenic data, demonstrates the striking ductility improvement obtained with A-286 at a 15%

(Text continued on page 58)

TABLE 2

CONDENSED TENSILE PROPERTIES

A356-T6 ALUMINUM PUMP HOUSING S/N 112

	Temp. °F	FTU (ksi)	FTY (ksi)	% El, 4D
Cope	RT.	35.0	27.8	3.5
	-423°F	45.0	42.5	2.0
Parting Line	RT.	33.0	23.7	3.9
	-423°F	39.4	-	2.0
Drag	RT.	38.0	28.0	7.0
	-423°F	49.0	37.5	3.1
Required by	RT.	35.0	25.0	6.0
Dwg. 1013496	-423°F	-	-	-

TABLE 3

COMPARISON OF ALLOY TENSILE PROPERTIES

A-286 AND D-279 ALLOYS

	Temp °F	FTU	FTY	Elong % in 4D	RA %
A-286	RT.	155	116	22	33.5
A-286	-423	219	149	29	27
D-979	RT.	193	138	12.5	15
D-979	-423	215	175	5.7	8

Coarse Grain size indicative of low ductility

Cope Section

Fine grain size indicative of higher ductility

Drag Section

Aluminum Alloy A356-T6 Sand Cast

Figure 12

Mark III Mod 4 TPA

Pump Housing S/N 112

Granular structure of Volute [illegible]100X room temperature yield strength sacrifice; however, no improvement at -423°F.

The following conclusions were drawn:

> The D-979 rotor material was anisotropic.
>
> The D-979 rotor material exhibited strain-rate sensitivity at -423°F by a significant decrease in elongation observed at the high strain rate.

Anisotropy was exhibited in the A-286 material by the higher ductility values and lower standard deviation for tangential specimens.

Material from the same two turbine rotors was used to compare notch toughness. Table 4 shows the toughness advantage of A-286 and the dependence of D-979 toughness on temperature. The following conclusions were drawn:

> The A-286 material toughness exceeded the D-979 material toughness by a factor of 4.3 at -320°F.
>
> The D-979 toughness at 400°F exceeded the toughness at -320°F by 84%.
>
> No significant toughness directionality was noted in either material.

TABLE 4

COMPARISON OF ALLOY NOTCH TOUGHNESS

Pre-Crack Charpy Impact Tests

Alloy	Test Temp	W/A
A-286	-320°F	3500 in-lb/in^2
	+400°F	3500 in-lb/in^2
D-979	-320°F	550 in-lb/in^2
	+400°F	1100 in-lb/in^2

W/A = Index of impact resistance/uncracked specimen area.

1.2.4 TPA BEARING DEVELOPMENT

Bearing tests were conducted to investigate the effect of coolant flow on bearing life. In order to adequately demonstrate this effect it was decided that a severe load condition would have to be applied to the thrust set. Accordingly, a load condition of 3000 lb on a half thrust set (5000-lb equivalent on a 60/40 load-sharing full set) was chosen as the test load for these tests. The tests were performed with the TPA first candidate roller bearings and the first candidate and alternate thrust sets.

A. INITIAL TEST-24,000 RPM, P/N 290122-19

An initial test with a TPA alternate half thrust set (P/N 290122-19) was conducted to demonstrate the effect of coolant flow on preventing bearing failure. The results of this 24,000-rpm test are shown in Figure 13. The initial coolant flow was 55 gpm (0.48 lb/sec), which was lowered to 50 gpm after about 25 minutes duration. The torque required to turn the shaft as indicated by the motor current began to rise exponentially and it appeared that a failure was imminent at 5 minutes. At this point the coolant flow rate was raised to 70 gpm (0.61 lb/sec) and the current dropped indicating a beneficial effect. Failure was similarly averted at 70 and 105 minutes by increasing the coolant flow each time. However, drive motor current dropped only a little below the maximum value attained up to that time. Evidently increasing the coolant flow prevented additional bearing damage; but, of course, did not repair existing damage.

At 122 minutes of operation at speed and load, the bearing failed catastrophically. The outer raceway shattered in several pieces and the inner raceway showed severe peening of the edge of the shoulder. The balls looked surprisingly good, but the retainer was completely destroyed.

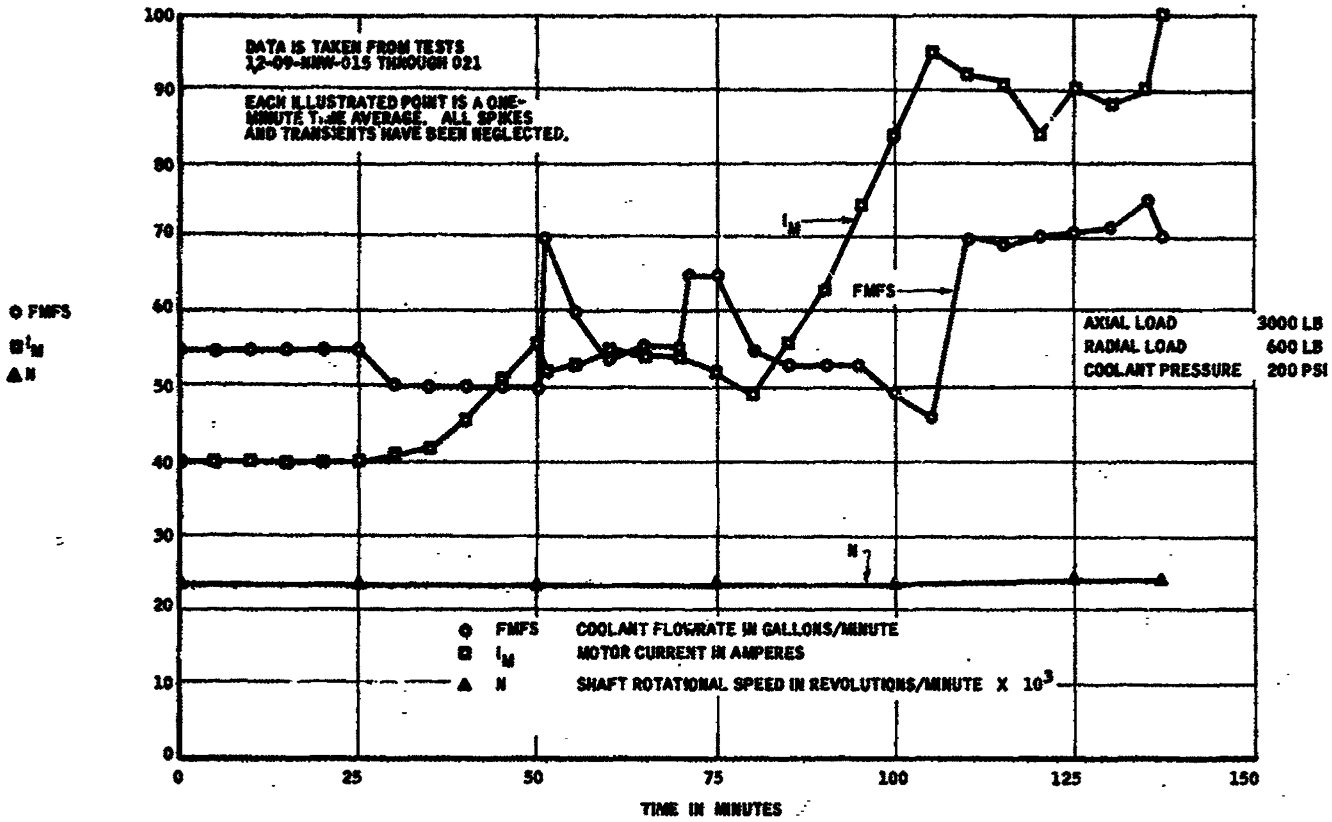


Figure 13

TPA Bearing Tests

Alternate Half Thrust Set P/N 290122-19

at 24000 RPM

B. SECOND TEST-28,000 RPM, P/N 290156-169

A test (the first under these conditions) was run at 28,000 rpm with 3000-lb axial load and 600 lb radial load using P/N 290156-169 roller bearing and P/N 290125-29 thrust set (TPA alternate). The test was terminated after 44 minutes at load and speed because the 100-amp shutdown limit was exceeded by the motor current. Post-test inspection did not disclose any gross bearing damage. The thrust set showed little wear of the retainer. Three rollers on each of the roller bearings showed heavy end wear, the rest showed light end wear. Bearing failure did not appear to be imminent. The 100-amp limit on motor current was established for a 24,000-rpm test. Experience has been that some bearing damage has occurred whenever the motor current exceeds 100 amp at 24,000 rpm. This limit was carried over into the 28,000-rpm testing. Under equal conditions, higher motor currrent is required to drive the bearing tester at 28,000 rpm than at 24,000 rpm (38 and 49 amp, respectively). Apparently the increased torque caused by friction from the six skewing rollers, combined with increased torque due to the high load and high speed, increased the required motor current to above 100 amp without the expected bearing damage.

C. TESTS-CANDIDATE BEARINGS

The first of three tests to investigate the effect of coolant flow with the TPA candidate bearings was completed. A half thrust set (P/N 240173-9) and roller bearings (P/N 290156-169) were operated at 24,000-rpm and 3,000-lb axial, and 500-lb radial loads, and at a flow rate of 0.2 lb/sec, which was about 22% of current TPA coolant flow. This first test failed after 7 minutes at rated conditions and results are plotted in Figure 14. The time scale has been expanded for clarity. Failure due to a continuous and rapid bearing temperature rise occurred at a relatively low friction torque, as indicated by a motor drive current of only 150 amp at failure.

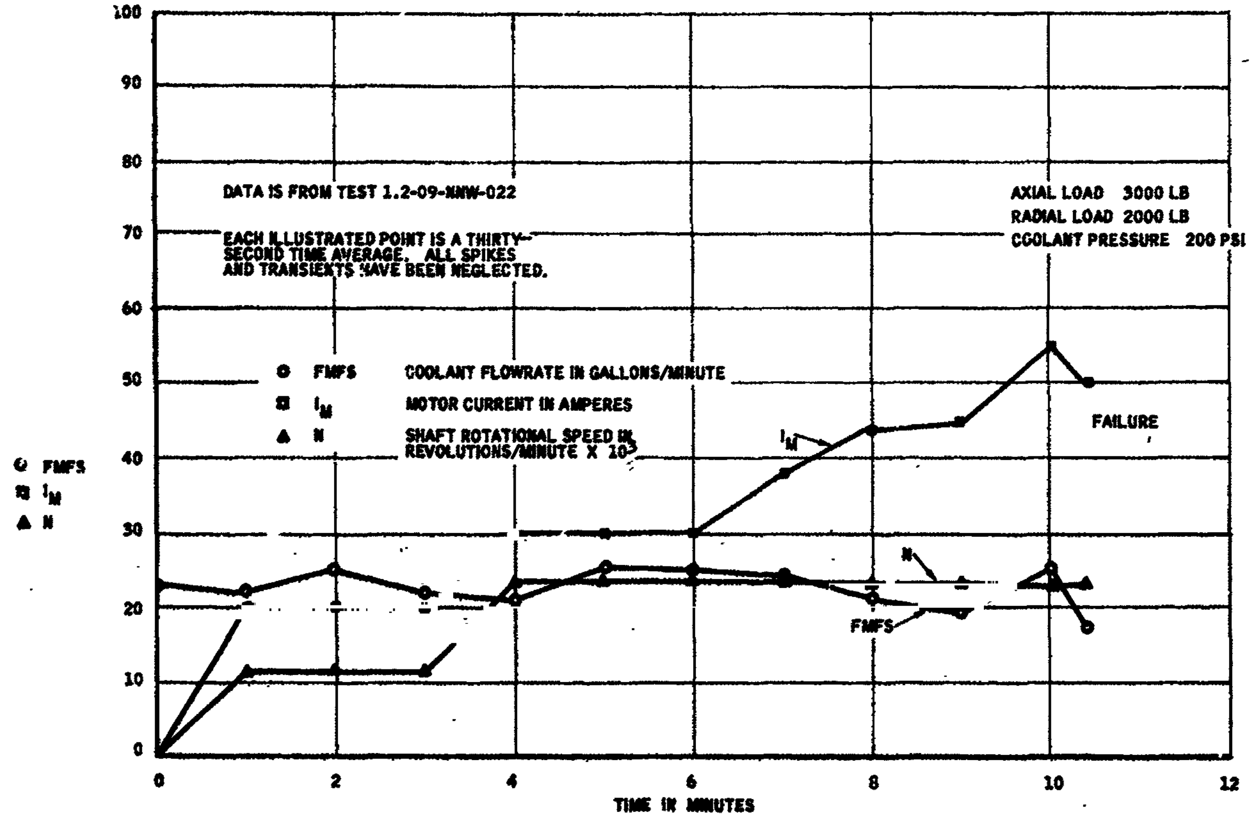


Figure 14

TPA Candidate Bearing Tests
Half Thrust Set and Roller Bearings
with Coolant Flow at 24000 RPM

Generally, failure occurs by an increase in motor current to a kill parameter of 100 amp. In this test overheating of the heavily loaded half thrust set resulted in the shutdown without the usual sharp sudden rise in friction torque.

Inspection of the retainer showed that it had undergone permanent dimensional changes because of centrifugal and ball forces during overheating. The retainer material of this bearing is an FEP (fluoro-ethylene-propylene) Teflon instead of TFE (poly-tetra-fluoro-ethylene) Teflon, as used in the alternate bearing (P/N 290125-29). The FEP Teflon has a softening point about 100°F lower than TFE Teflon, and is therefore more sensitive to an overheating condition.

Because of geometric considerations (16 7/16 in. balls, 29° contact angle, double gothic close curvature raceway of 52%), the heavily loaded half thrust set containing the FEP retainer generated sufficient frictional heat at the low coolant flow to cause the FEP retainer to fail long before damage of the metal surfaces was obtained. In contrast, the 290122-19 or 290125-29 half thrust set (TPA alternate) at the same conditions was able to operate for 42 minutes before raceway and rolling elements showed overheating and incipient damage resulted, (as reported in the previous Progress Letter). In this test there was no visible damage to the TFE retainer. The two latter TPA alternate bearings are nearly identical and contain 12 1/2 in. balls, at 24° contact angle, with curvature of 51% in the outer raceway, 54% in the inner raceway. This geometric configuration appears to generate less heat and thus can survive longer at lower coolant flow.

1.3 REACTOR SYSTEM INTEGRATION

A. TEST DOCUMENTATION REVIEW AND COORDINATION

All NRX-A3 Control Room Operating Procedures and Disassembly and Post-Mortem Procedures were reviewed and approved for use and requested changes to the NRX-A3 Test Specification were reviewed.

B. ON-SITE TECHNICAL ASSISTANCE

Technical assistance was supplied to [illegible] by Aerojet in the form of representation on the Test Specification and Procedure Review Board, Test Review Board and the various assembly and data teams that were active on NRX-A3.

C. NRX-A3 TESTING

During this report period, work was completed on the NRX-A3 Test Series, with the exception of final Post Mortem analysis. Figures 15 and 16 show the test setup and powers of the test firing conducted on 23 April 1965. This test series completion included work on Experimental Plans, in the following sequence:

EP-1	4-7-65	Initial Criticality and Flow Test
EP-2	4-14-65	Power Calibration and Control Drum Worth Test
EP-3	4-21-65	Neutronic Calibration, Phase II Flow, and Scale-Down Power Test
EP-4	4-23-65	Power Test
EP-IIIA	5-13-65	Flow and Scale-Down Power Test
EP-5	5-20-65	Re-Start and Power Test
EP-6	5-28-65	Alternate Start-up - Medium-Power Test

EP's 1, 2, and 3 were check-out tests normally conducted on all reactor tests, including those related to power limited safety circuits and pump checkout. The power test conducted during EP-4 included a reactor operation at approximately 100% design point for 2.3 minutes. At that time a reactor scram from full-power, induced by a turbopump overspeed signal, resulted in the termination of the test. A complete detailed review followed, concerning possible effects on both nuclear and non-nuclear components, which led to the decision to restart the test assembly at the 100%-design condition. This was done in EP-5, at approximately 100% power for 13 minutes. The final experiment (EP-6), on 28 May 1965, was a control and medium power mapping test up to 400 mw, and ended the NRX-A3 test series.

D. NRX-A3 DISASSEMBLY AND POST-MORTEM EVALUATION

Disassembly and Post Mortem evaluation of the NRX-A3 components was initiated on 2 June 1965, and was not complete at the end of this report period. However, initial evaluation indicated that, generally, the components appear to be in excellent condition. Some corrosion and undercutting of the fuel elements was noted at the hot end of the elements, but the pheripheral corrosion that occurred during NRX-A2 was not present to the same degree. The condition of the non-nuclear components was excellent. At the present time, no significant problems are anticipated in the utilization of components of these types for future testing.

E. ENGINE/REACTOR SYSTEM INTEGRATION

The NRX/EST fuel-element production at WAFF and Y-12 was monitored, and weekly status reports of fuel-element production and problems reflected the effects of fuel-element production upon schedules, expenditures, process development, and fuel element materials research.

Proposed specification changes and modifications for NRX-A5 fuel production were reviewed, and recommendations were made in concert with SNPO-C.

(Text continued on page 68)

Figure 15

NRX-A3 Hot Run, 23 April 1965
Looking Northwest from R-MAD Building

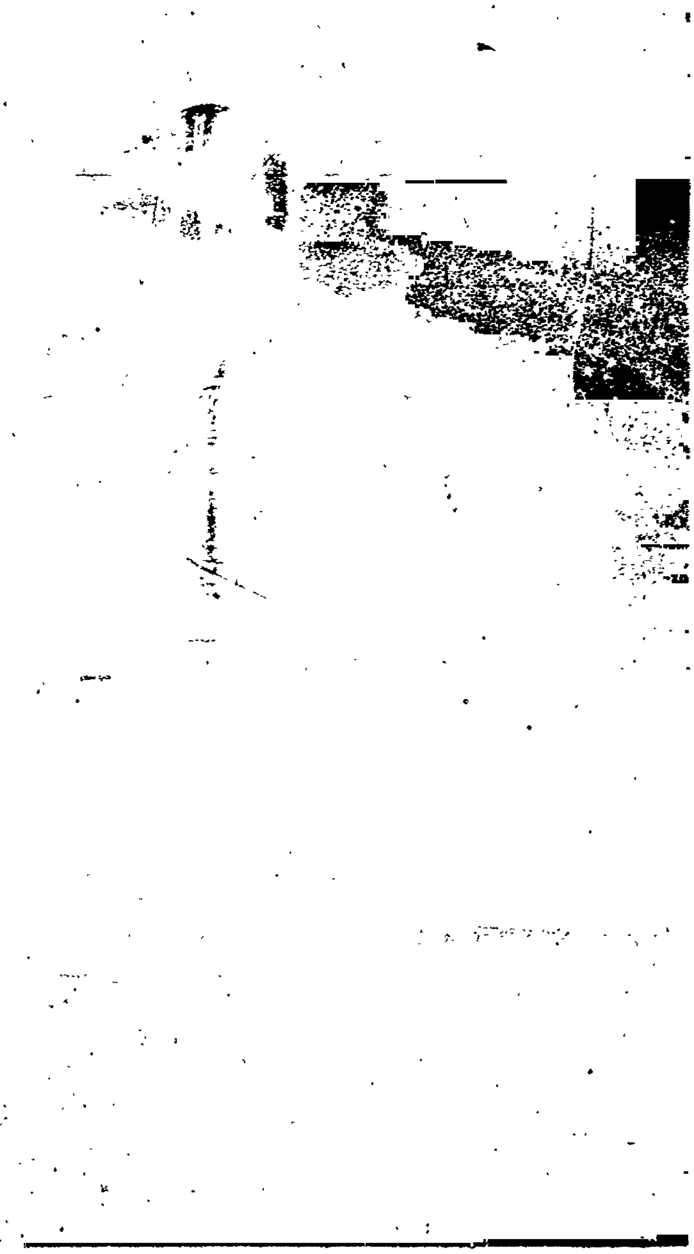


Figure 16

NRX-A3 in Test Position

23 April 1965

General review of WANL progress in the Component Test Program continued, including attendance at the Monthly Component Test Review Meetings. All available test data and reports were reviewed, with special emphasis placed on the review of:

EML-60	Core Effective Gap Tests
FFL-17	Plugged Core Tracer Gas Tests
HHT 1 and 2	Fuel-Element Corrosion Tests
HHT 15	Interstitial Corrosion Tests

Full coverage was provided for NRX-A3 disassembly and post-mortem work at NTO, including providing cognizant engineers for fuel corrosion information, reactor mechanical assembly and structural information (including non-nuclear hardware corrosion data), and nuclear, thermal, and fluid-flow information as applicable. The information obtained from the A3 post-mortem will provide valuable background in determining the adequacy of hardware design requirements, and demand schedules, and changes required as a result of reactor testing.

Representation was maintained on the NRX/EST, CFDTS, and XE-1 Project Organizations, providing nuclear subsystem integration information. A study was completed on CFDTS nuclear subsystem temperature limitations for heated core testing. This study showed that testing at the proposed temperature levels was not feasible without severe degradation of reactor core components.

AGC Specification 90017, Nuclear Subsystem Specification for the XE-1 Engine was prepared. This specification covers the mechanical, nuclear, thermal and fluid-flow nuclear subsystem design requirements of the XE-1 Engine.

Investigations were made of the feasibility of removing all shipping poison wires from the NRX/EST core at R-MAD and of the inverse count-rate curve and pulse-neutron generator methods of determining shut-down reactivity. Procedures were developed in conjunction with NTO for pulling poison wires, while insuring that a $2 shut-down margin is maintained.

The OPTION, COMAT-2, and WANL-S4 codes achieved operational status at Aerojet, thus establishing better sources of information for systems analysis, on the NRX/EST and XE Engine cool-down requirements.

Mode-of-failure analyses of the dewar deludge system, the commercial power system, and on-site power generating system were performed in support of the NRX/EST program. There are 14 possibilities of single failures which could lead to a loss of power at Test Cell "A" during a test.

The need for a fluid-flow interface document became apparent, and meetings between WANL and REON analysis personnel were correspondingly established which resulted in a State-Point Control document, approved by REON, and in the hands of WANL for review and approval during this period.

The required technical review of 130 WANL procurement packages was coordinated with REON subcontracts and other technical departments.

1.4 THRUST CHAMBER ASSEMBLY (TCA)

1.4.0 ASSEMBLY

Design cognizance, technical liaison, and technical administration, of TCA activities continued, as required.

Interface review of TCA hardware continued (in conjunction with the review of Subtask 1.2 hardware) to ensure satisfactory fit-up prior to the NRX/EST assembly.

A test plan was initiated for a Hot Bleed Port Nozzle - Pressure Vessel Hydrostatic Test.

1.4.1 NOZZLE DEVELOPMENT

A. REPORTS

These Test Reports were completed:

RN-TM-0192, Final Test Report on Test Series 1.2-04-NNS Injector Development and Heat-Transfer Tests on S/N 012 Aluminum Nozzle

RN-TM-0186, Final Test Report on U-Tube nozzles S/N 008 and S/N 009

RN-TM-0177, Investigation of adapter coolant tube erosion during Test Series 1.2-07-NNJ-005

RN-TM-0195, Test Report on hot-bleed-port Test series 1.2-09-NNN conducted with an aluminum jacketed nozzle S/N 013 and bolt-on bleed port

B. HOT-BLEED-PORT, U-TUBE CONFIGURATION NOZZLE AND BLEED PORT ASSEMBLY WITH BOLT-ON BLEED PORT TO NOZZLE JOINT

1. Nozzle S/N 008

The diagnostic testing to determine the validity of the ultrasonic inspection of the tube-to-tube-to-jacket braze joint has been conducted, and memoranda reports have been written. In general, the tests were not conclusive enough to warrant any further work on this method of braze joint inspection.

Work is now continuing on the structural test which will use this shell. This testing will verify analytical stress evaluation of the bleed-port boss and the pressure vessel-to-nozzle joint.

2. Nozzle S/N 021

The thermocouple pass-throughs, and most of the instrumentation bosses on the inlet torus have been deleted, to expedite the completion of this joint. The bolt-coolant circuit and core-support-flange tabs will not be installed. Full instrumentation fittings are installed in the area of the hot-bleed port. The tube-pressure drop and temperature-rise profile instrumentationwere incorporated, and the nozzle has been instrumented to give further data with regard to heat-transfer (as noted in the last progress report).

Water-flow tests of this nozzle indicated an average flow deficiency, from the tubes bisected by the hot-bleed-port, of about 11%. After adjustment of the set screws, the maldistribution was reduced to about 8%.

After contouring the 26 feed and exit slots around the bleed port and installing the port liner, the nozzle was ready for tube installation by the end of April. This was accomplished, and the tubes were brazed to the nozzle before the middle of May. Weld installation of all component parts and final machining were completed early in June.

During the GN_2 leak test, 20 leaks were detected and repaired. Deposition of braze patches for heat-transfer studies and the various hydrotests were completed late in June. The nozzle has now been cleaned and is being built-up into a simulation test assembly.

All testing under this item has been completed and reported in the previous quarterly letter. All future testing will be conducted and reported under Item 1.4.7.

1.4.2 THRUST STRUCTURE

A. CFDTS THRUST STRUCTURE

Work on the CFDTS UTS proof-test report has been completed, and this report will be published next quarter. Evaluation of the CFDTS LTS proof test data was continued.

B. XE UPPER THRUST STRUCTURE (UTS)

Preliminary design of the UTS to incorporate remote assembly/disassembly at the UTS/shield interface was continued during the quarter.

Preliminary stress analysis of UTS changes to incorporate remote assembly and disassembly of the UTS and shield was performed.

A transient thermal analysis of the UTS and pump inlet line connection was made to evaluate the capability of the Cryogenic Laboratory in achieving the maximum line cool-down for the UTS thermal stress test. The test objective is to demonstrate and evaluate the structural integrity of the connection with the line at LH_2 temperature (-416°F at 40 psia). Results showed several satisfactory alternatives exist using various run and storage tank sequencing.

C. UPPER THRUST STRUCTURE DESIGN AID

Figure 17 shows the initial full size XE-1 type UTS design aid.

The fabrication of this unit was completed by Aeronca Manufacturing Corporation on 24 June 1965. Completion was delayed three weeks, primarily because of match plate availability problems. To facilitate the TSA/UTS* interface test program use, this particular unit was fabricated without the removable panels, which will be installed on

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* TSA/UTS = Test Stand Adapter for the Upper Thrust Structure

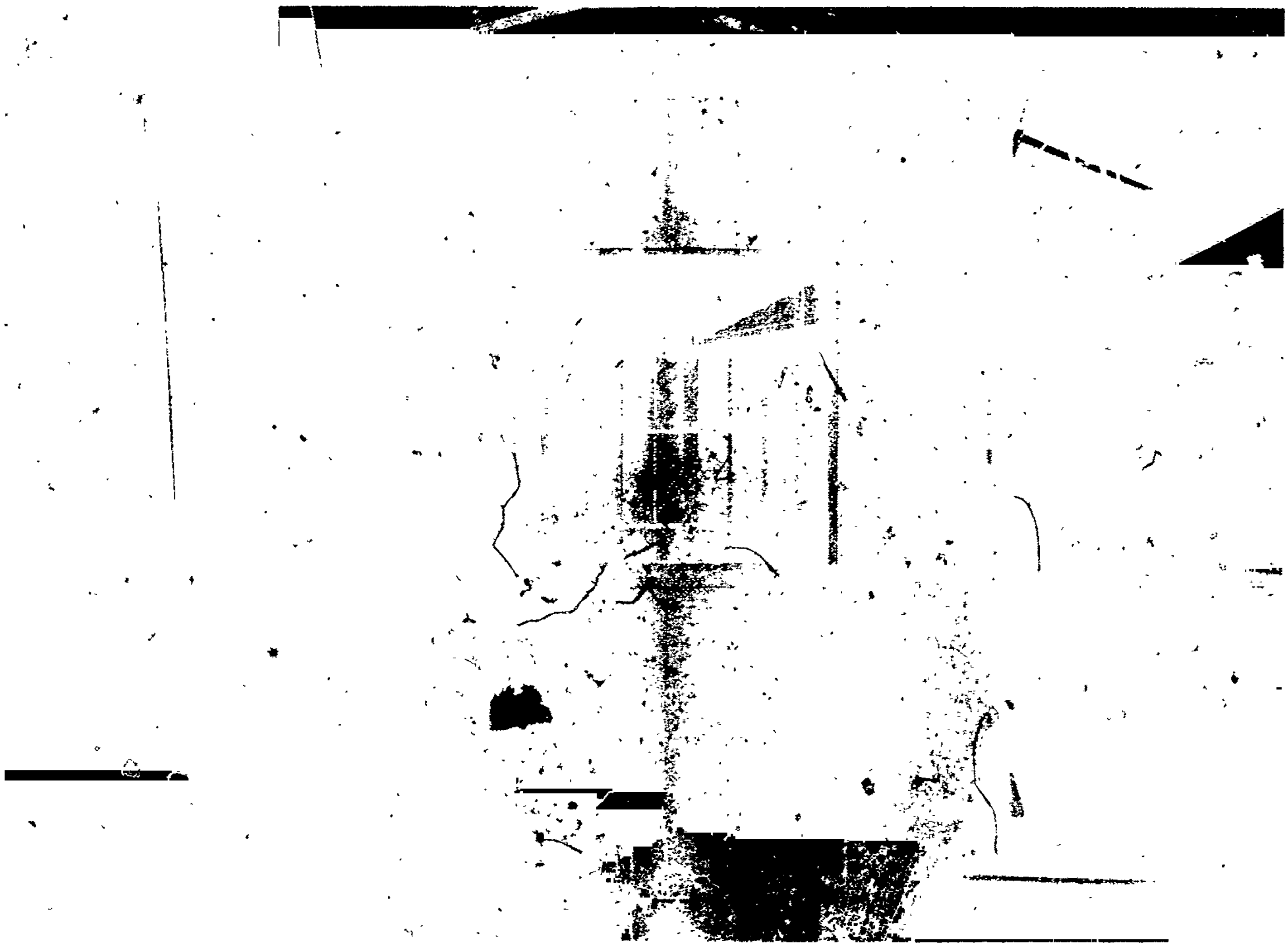


Figure 17

XE-1 Upper Thrust Structure

Design Aid

all subsequent units. New important features of the UTS design aid are the upper plate with interface cutouts and attachment holes for electrical connectors and various lines and the external guide pins, which are shown in Figure 18. As a means of improving strength, quality, and lowering the cost, the end fittings were made from 2014-T6 aluminum alloy forgings (See Figure 19), which contrast with the earlier units, which were made from welded 6061-0 aluminum alloy plate and heat treated to the T-6 temperature.

The assembly jig previously built to assemble the 60-inch long CFDTS UTS was modified to incorporate the 94.75-inch XE-1 length in this unit. Forging dies were provided to fabricate the aluminum end fittings.

Delivery of the design aid will be made to Aerojet in July following the structural testing of the unit, also to take place at Aeronca.

A test plan for the UTS design aid structural test was completed, with these objectives:

To demonstrate structural integrity for XE-1 loads.

To obtain deflection data including a thorough survey of the remote interface deflections due to simulated electrical connector loads.

D. LOWER THRUST STRUCTURE (LTS)

Preliminary design effort was initiated on the XE-1 lower thrust structure, with primary emphasis in the area of the LTS-PV joint. A preliminary stress study was completed on a LTS/PV joint concept.

A transient thermal analysis was initiated of a redesigned lower thrust structure flange ring and redesigned pressure vessel (A5 type), forward flange. The purpose of the analysis is to determine the thermal effect on the PV closure-cylinder bolt and to provide thermal profiles of the lower thrust structure for use in stress calculations.

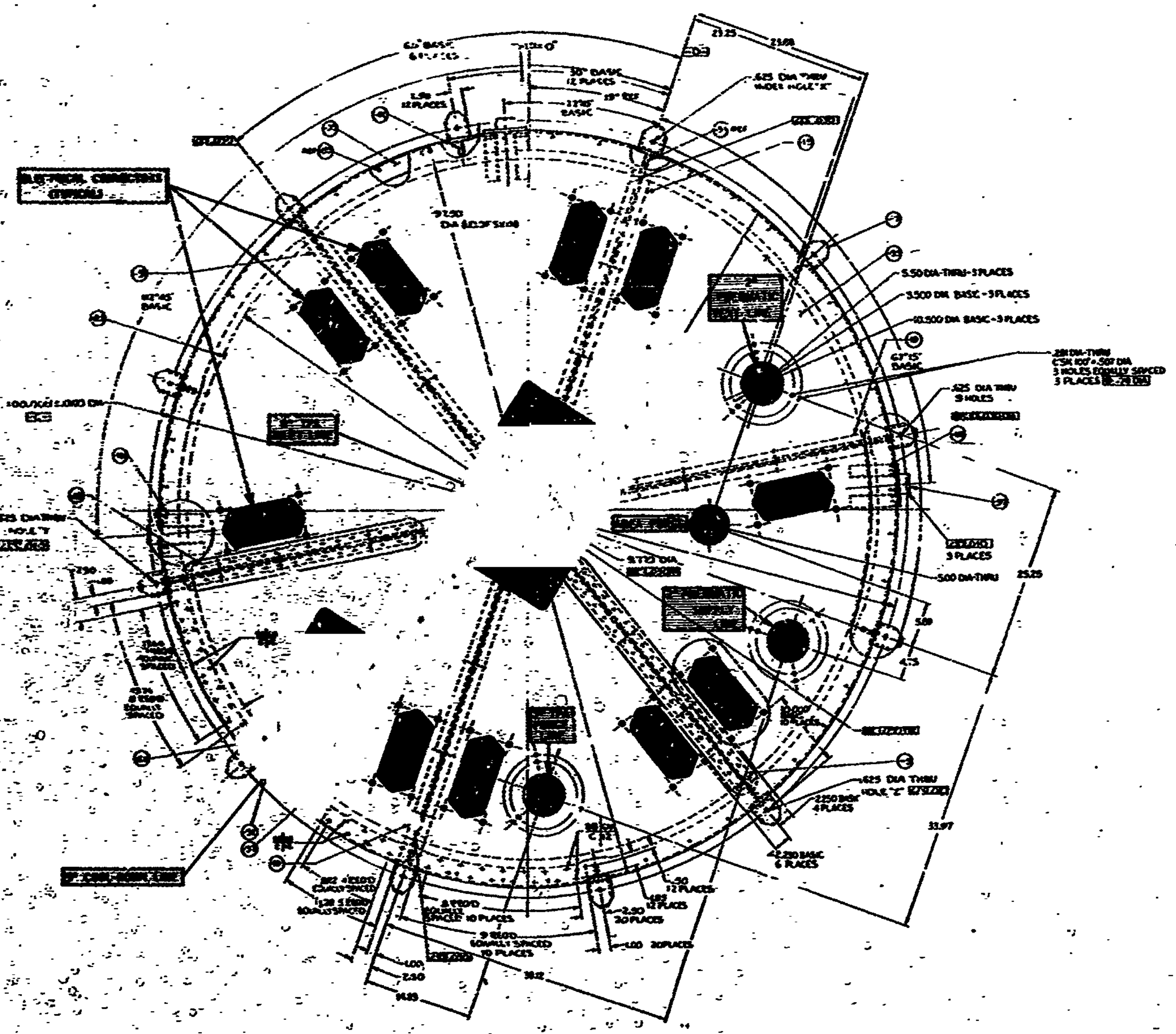


Figure 18

XE-1 Upper Thrust Structure

Design Aid Details

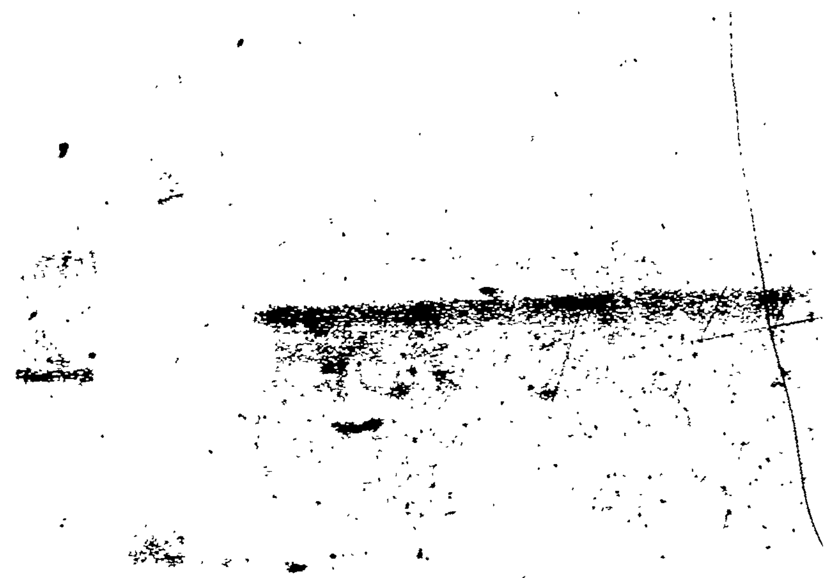


Figure 19

XE-1 Upper Thrust Structure
2014-T6 End Fitting Forgings

1.4.3 PRESSURE VESSEL

A. SEALS

The evaluation report for the Cryogenic Test Series II of the NRX-A Pressure Vessel Closure Seal was published as REON Report RN-TM-0209. The series evaluated AGC Mod III PV closure seals, P/N's 705616 and 705620, inboard and outboard of the bolt circle respectively, and a Tetrafluor seal, P/N TVS5-1648.

The evaluation report for the Pressure Vessel-Nozzle Seal Assembly Confirmation Test (1070N) was published as REON Report RN-S-0158.

The following pressure vessel seals are being fabricated:

6 each Mod I outboard cylinder/closure seals, P/N 286769, and P/N 286770

6 each Mod II cylinder/nozzle seals, P/N 702154

B. MATERIALS ENGINEERING

A summarization of pressure vessel materials data was completed and was published as REON Report RN-TM-0157.

C. NRX-A3

Engineering coverage was provided at NRDS for the disassembly of the NRX-A3 pressure vessel components.

An evaluation was initiated of the pressure vessel assembly during the NRX-A3 test program, to include the pressure vessel cylinder, closure, seals and fasteners.

Analyses were initiated of NRX-A3 test data, to improve the mathematical model of the pressure vessel used for temperature predictions; and of NRX-A3 pressure vessel thermal strains, as an aid in the interpretation of pressure vessel strain-gage data.

D. NRX/EST

The NRX/EST pressure vessel details, which differed from the previous NRX design, were analyzed and the results included in RN-TM-0217, Structural Analysis of Non-Nuclear Components for NRX/EST Engine System (Part I) Summary.

The NRX/EST pressure vessel cylinder S/N 007 (Figure 20), and fabrication of NRX/EST closure S/N 008 (Figure 21), at The Marquardt Corporation, Ogden, Utah were reworked. The vessel was delivered to WANL, at Large, on 8 June 1965.

A test program was initiated to determine the structural integrity and sealing characteristics of the Marman Clamp/Conoseal configuration chosen for the diluent and emergency cooldown ports on the NRX/EST pressure vessel closure (Figure 22). The test fixture has been fabricated (Figure 23) and successfully proof tested, and seal testing at both ambient and cryogenic conditions is continuing.

E. NRX-A4

A preliminary design layout was initiated for the XE-1 pressure vessel/thrust structure interface.

F. NRX-A5

Detailed pressure-vessel design drawings were completed for NRX-A5. The new pressure-vessel design proposes a Marman Clamp/Conoseal configuration for the guide tube/closure joint and structurally refined closure and forward cylinder flanges to improve the joint behavior and sealing capability in this area. Final drawing release is awaiting approval of ICOR's to ICD 1010045.

G. PV REWORK

S/N 007 pressure vessel closure for a reactor-only NRX-A4 test was reworked, and is now in Aerojet stores. Seal test pressure vessel S/N 009 was reworked. The modification was required to provide a satisfactory vessel for testing Mod I outboard cylinder/closure seals.

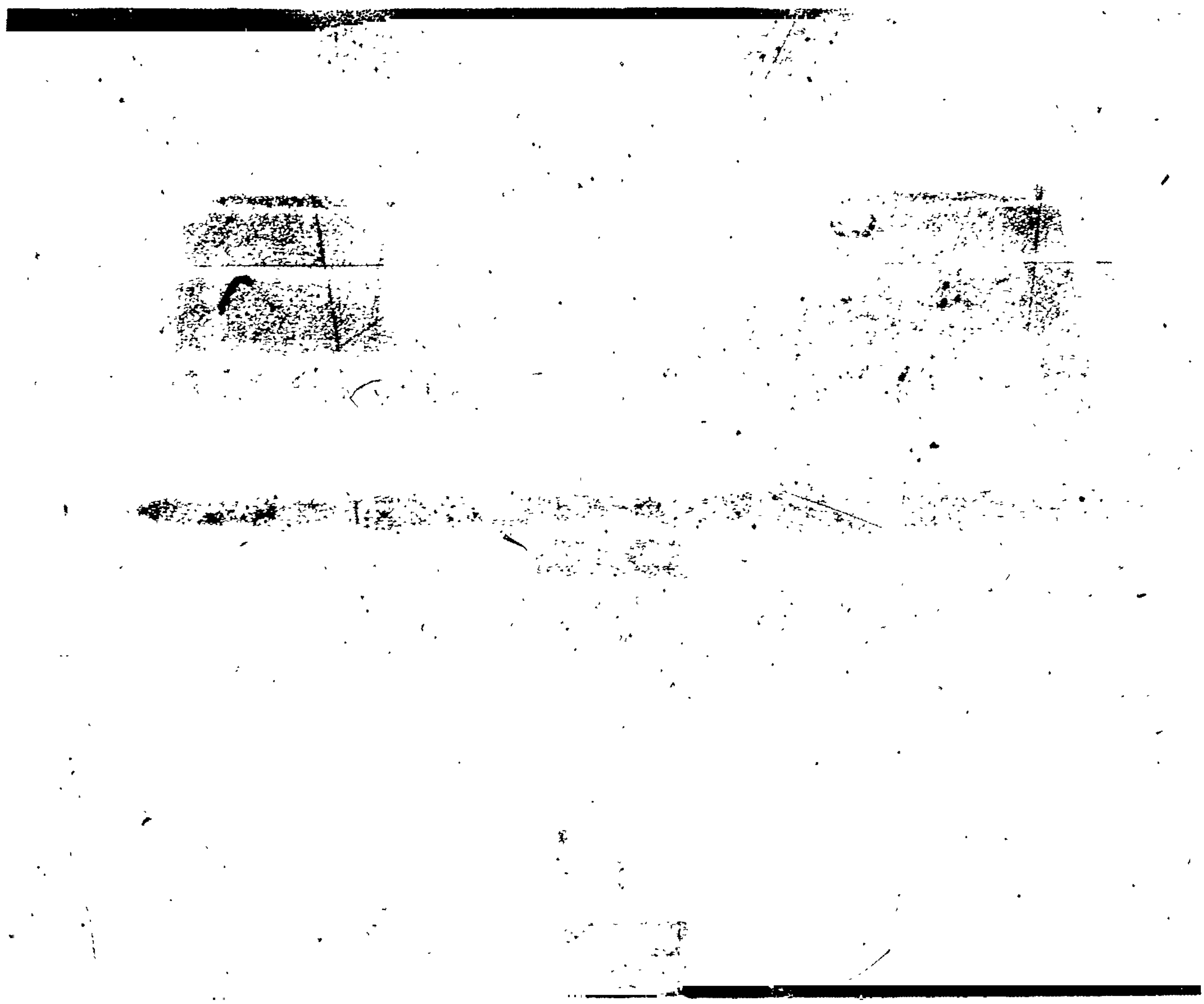


Figure 20

NRX/EST Pressure Vessel

Cylinder

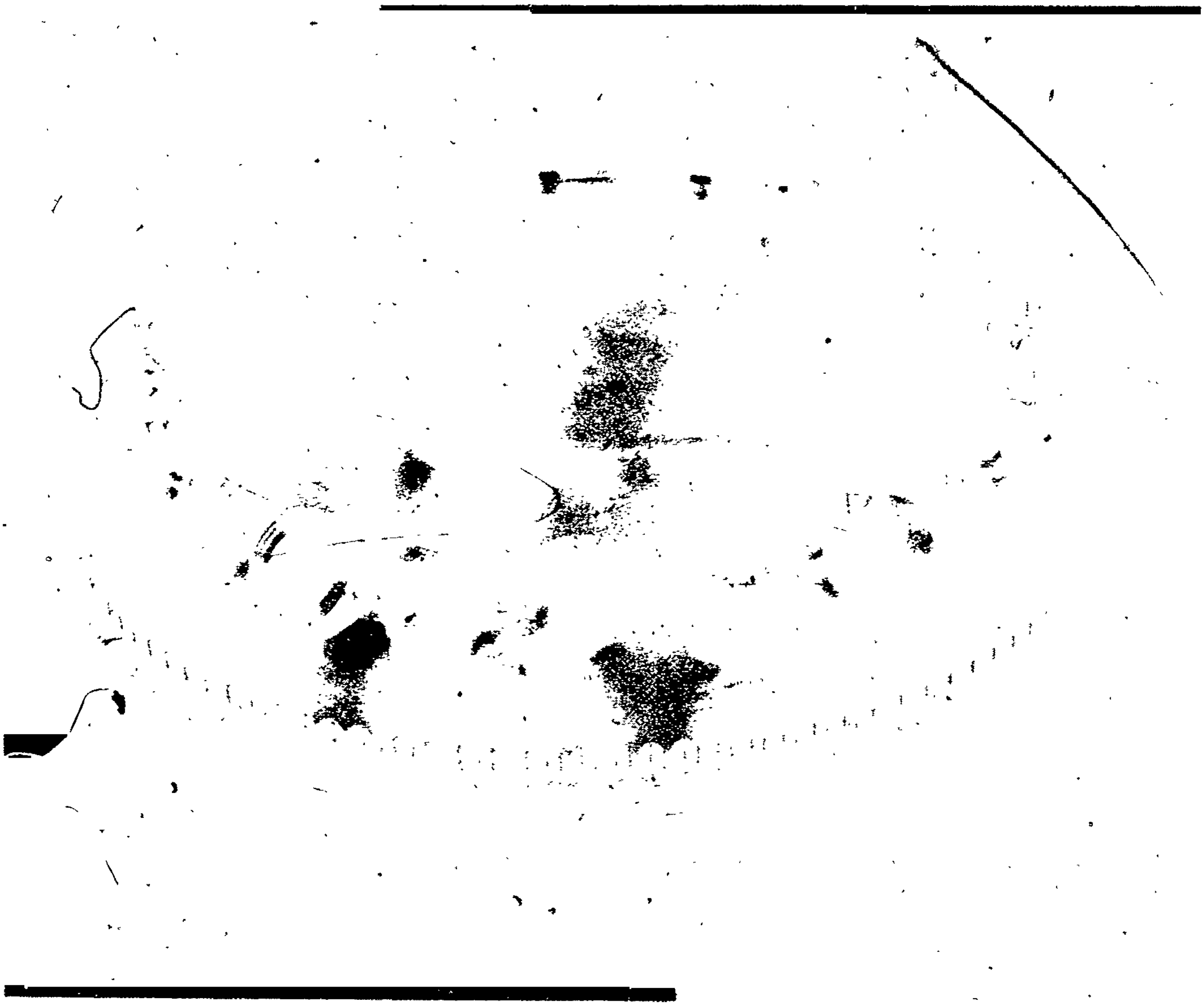


Figure 21

NRX/EST Pressure Vessel Closure

Figure 22

NRX/EST Pressure Vessel Closure
Diluent/Closure Joint Test Assembly

Figure 23

NRX/EST Pressure Vessel Closure

Diluent/Closure Joint Test Fixture

1.4.4 TCA LINES

A. NRX/EST AND XE LINES DESIGN

Design of all NRX/EST lines and supports, including the vent, hot bleed by-pass and diluent lines, and the supports required for the valves was completed prior to the end of this quarter. In addition, the pump discharge line was revised to include only three internally gimbaled bellows instead of the original six.

The XE-engine configuration design continued with further definition of functional and interfacing requirements and orientation of line parts and attaching components.

B. HEAT TRANSFER AND STRUCTURAL ANALYSIS

Heat-transfer analysis was performed on several different NRX/EST support bracket configurations to determine cooling requirements.

A frame analysis program was utilized to determine the end restraint reactions caused by thermal and mechanical loadings for the NRX/EST pump discharge, turbine inlet, and diluent lines. Comparison of analyses considering the lines with and without intermediate supports above the shield showed less severe end loadings where no intermediate supports were used. Vibration analyses were conducted on each of the unsupported lines to determine the natural frequencies, which were all shown to be considerably less than 100 cps. These frequencies are below those induced at the operating speed of the TPA (400 cps) and the resonant frequency of the nozzle (239 cps*). Based on the above results, the use of the intermediate supports were deleted on NRX/EST. A summary of the NRX/EST TCA lines analyses was incorporated in Report REON TM-0217.

*Reference WANL-TME-979, NRX-A2 Vibration Survey EML 55, September 1964 (C-RD)

C. HARDWARE

During this quarter, NRX/EST TCA line hardware was completed for the pump discharge and vent lines, which were shipped to NRDS. Portions of the turbine inlet line were also completed, but the turbine inlet line jacketed section, diluent line and hot bleed by-pass line segments, diluent valve support, and hot bleed by-pass line support are in various stages of fabrication, with completion and delivery to NRDS expected in July.

Figure 24 shows the 5-inch pump discharge line flange and bellows assembly designated as the "Across-the-Shield" segment. Made of Type 347 stainless steel, the assembly has a Marman Cono-seal flange on both ends and contains three internally gimbaled bellows. The bellows allow relative movement during assembly with the engine to overcome tolerance stackup and operational stresses due to thermal and mechanical loads. Figure 25 shows the 2-inch vent line manifold assembly. Made of Type 304L stainless, this segment, together with the other two noted above, are located below the shield with the ends connected to the EST inlet line and the pump discharge line. The tee outlet interfaces with a facility line. Marman Cono-seal flanges are also used. A wire braid bellows, shown with protective covering, permits flexibility in the line. The elbows are commercial items to reduce costs.

A turbine inlet jacketed section (P/N 1013495-9), identical to the NRX/EST unit, is being fabricated for development testing with hot-bleed-port nozzle S/N 021. Completion is expected early in July.

An NRX propellant feed line was modified to interface with the revised facility propellant feed system. The line was subsequently delivered to NRDS for NRX-A5 use.

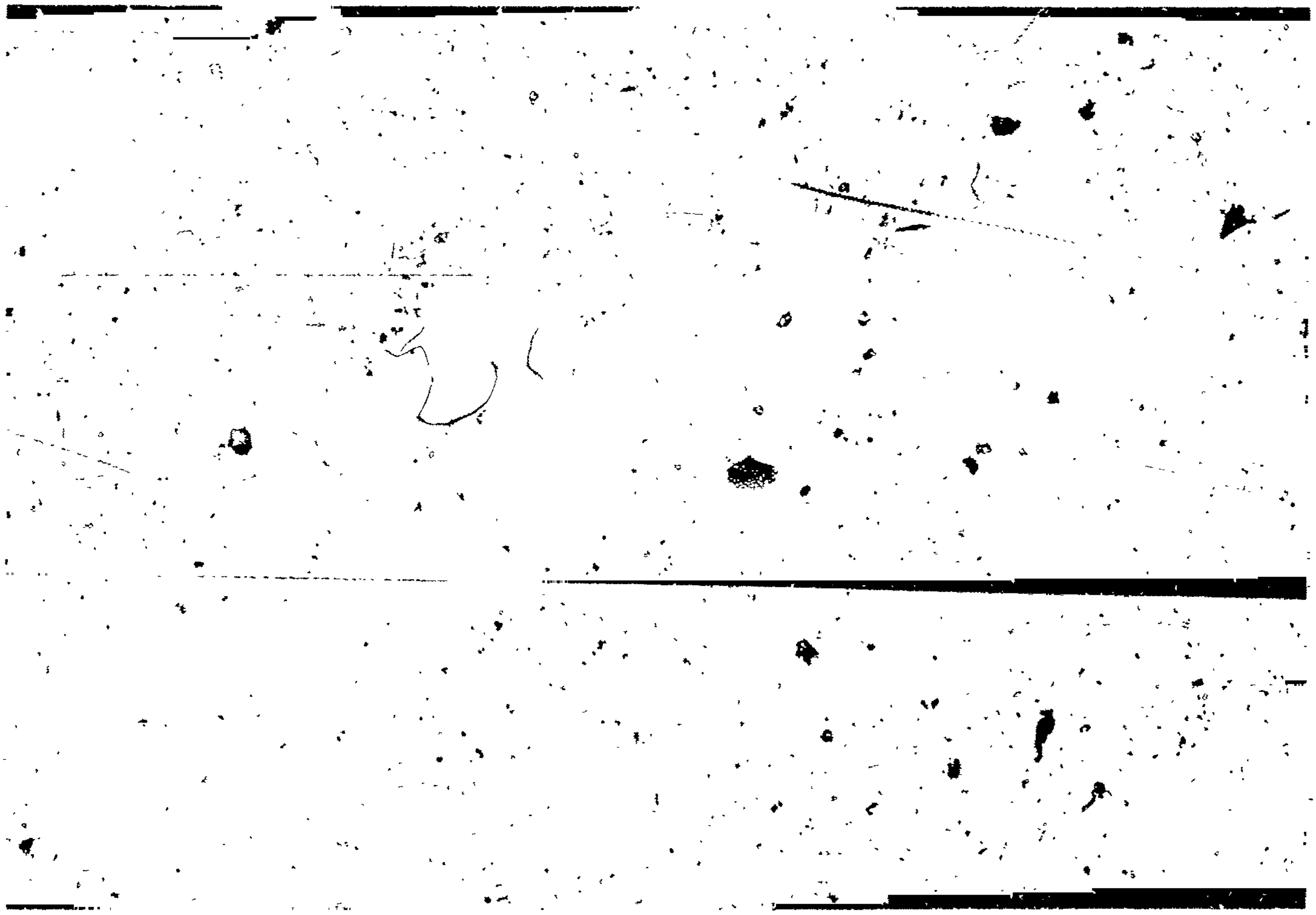


Figure 24

NRX/EST Pump Discharge Line
across the Shield Segmement

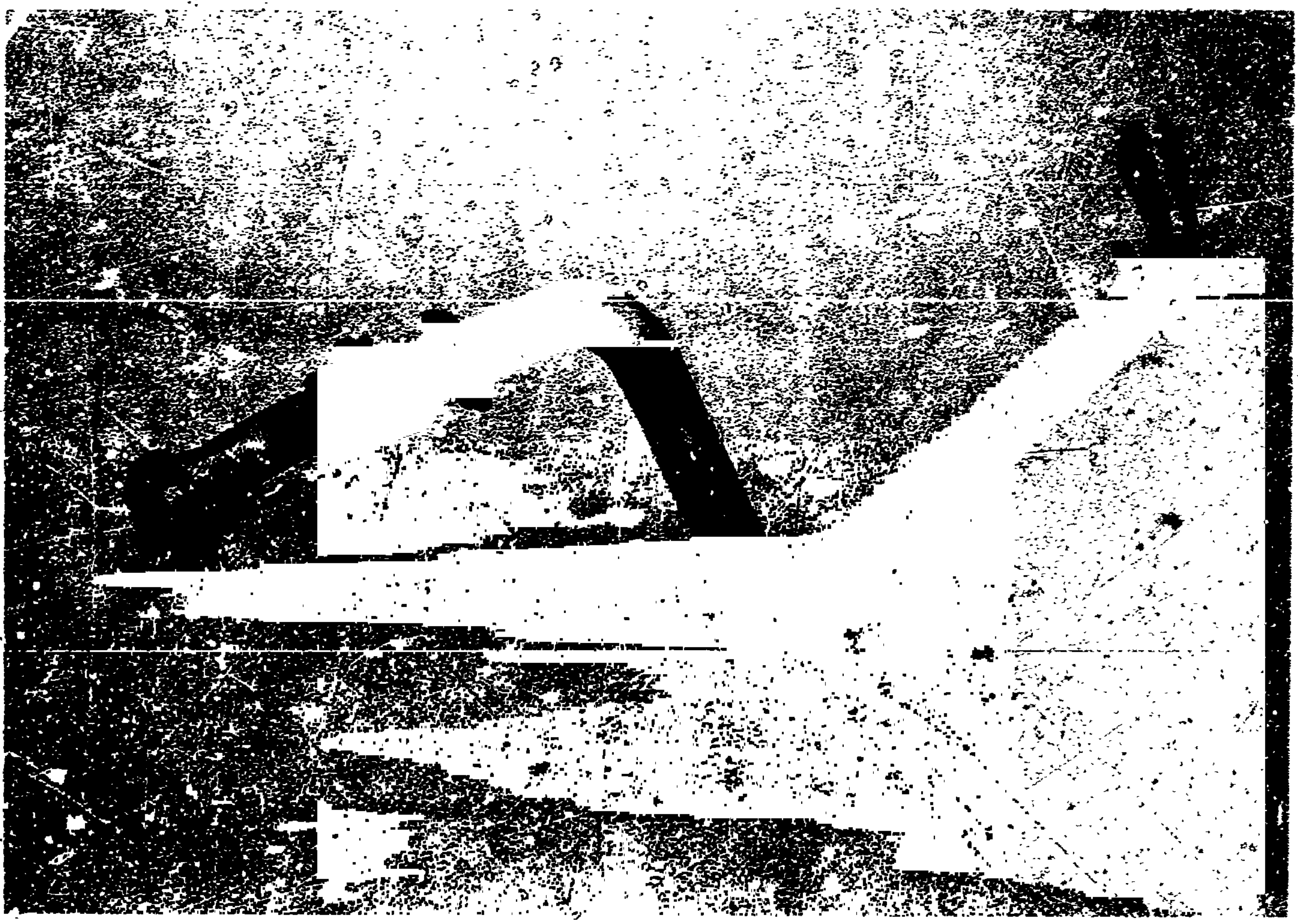


Figure 25

NRX/EST 2-in. Vent Line
Manifold Assembly

1.4.5 REACTOR NOZZLES

All activities within the scope of this item were completed upon the delivery of the NRX-A3 nozzle (S/N 022) to subtask 1.1.

1.4.6 APPLIED RESEARCH PROGRAM

A. METALLURGY

The brazing process for the NERVA nozzle has been firmly established and the appropriate specification has been issued.

B. GAS-SIDE HEAT TRANSFER

Currently recommended values of the coefficient C_g in the simplified Bartz equation have been calculated for both the nuclear and chemical simulation cases, and are shown in Figure 26. The dashed line represents the theoretical values at reactor conditions; the solid line shows the correction applied upstream of the throat to allow for gas impingement, and indicates the values currently used for nuclear testing of the NERVA nozzle.

The theoretical curve for the chemical simulation C_g's is shown by the broken line in Figure 26. This curve is based on boundary-layer growth from the adapter inlet and gas properties calculated by the Aerojet 287A computer program.

C. LIQUID-SIDE HEAT TRANSFER

The graphical comparison of the heat-transfer coefficient computed using the Hess and Kunz film temperature correlation and the experimental coefficient, reveals that an inconsistency exists between the data and the equations proposed for correlating the data. To obtain the experimental test data, scale-model tests were conducted in electrically heated tubes.

One thing that is peculiar to all these tests is the method of obtaining test data. The scale-model heat transfer tests were generally performed in constant diameter uniform-wall-thickness electrically-heated tubes, with the result that the heat flux was essentially uniform and the mass velocity was constant throughout the length of the tube, and therefore, the heat flux parameter

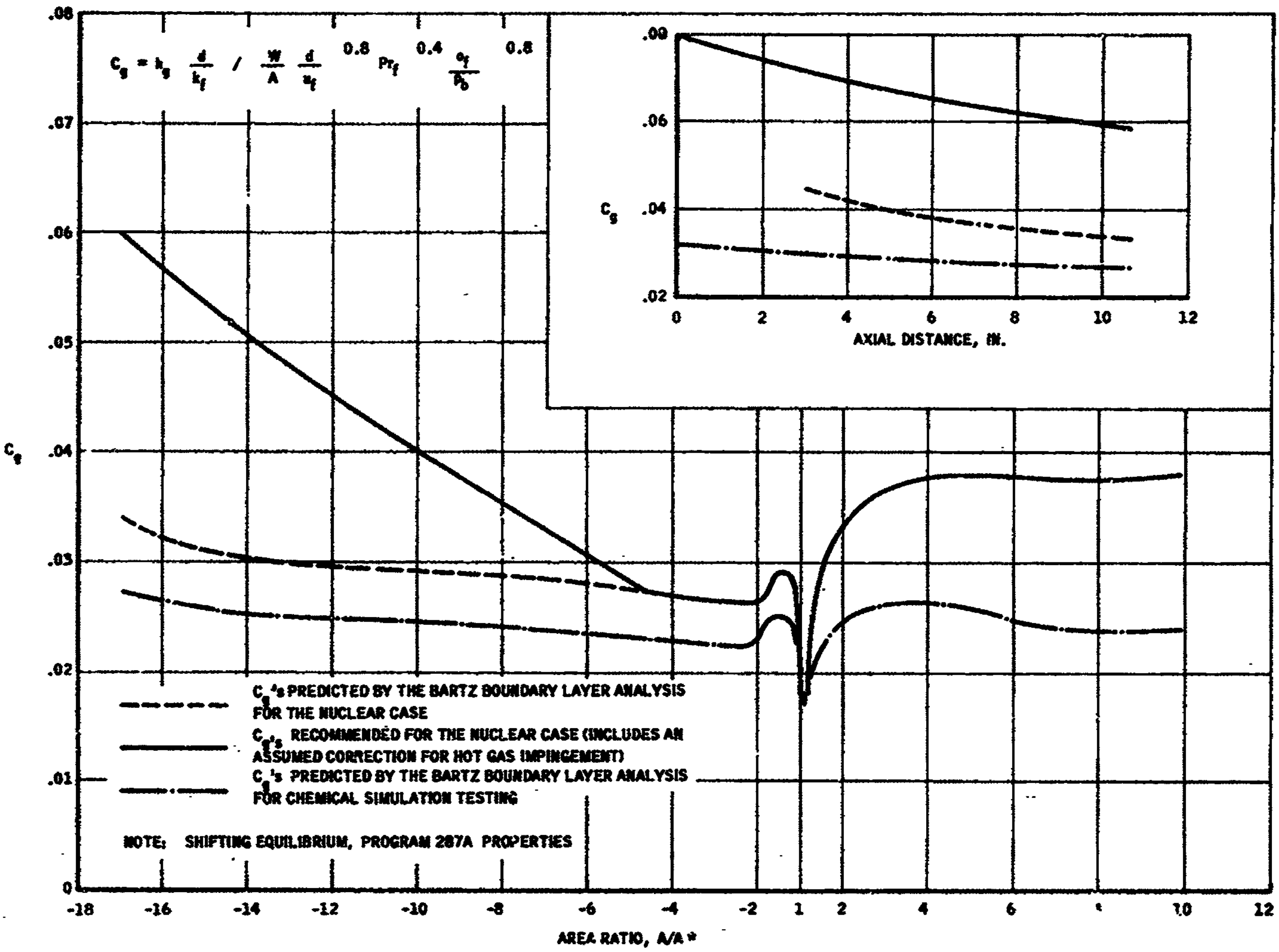


Figure 26

NERVA Nozzle - Nuclear and Chemical Simulation Testing

Recommended C_g Values

$$\frac{(Q/A)\ D^{0.2}}{G^{0.8}}$$

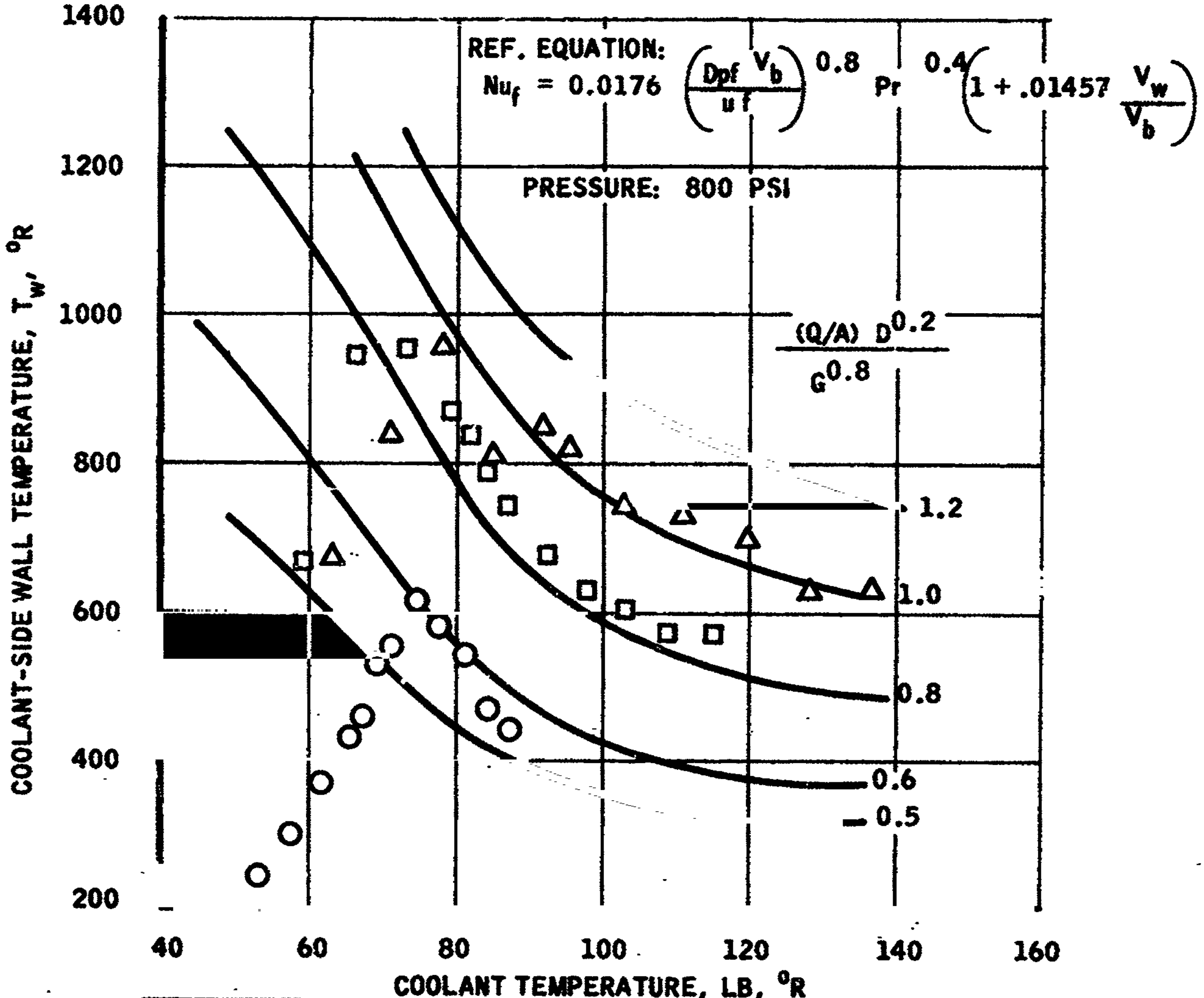
is essentially a constant throughout the heated length. The local coolant temperature is computed assuming uniform heat addition along the tube, and the local wall temperature is calculated from the measured outer wall temperature.

Figure 27 shows how the wall temperature varies with coolant temperature for lines of constant heat flux parameter, as predicted by the Hess and Kunz equation with the modified coefficient, as is currently recommended for predicting the heat-transfer coefficient in straight tubes. Included on this plot are some of the data showing the relationship between the wall and coolant temperatures for essentially constant heat-flux parameters as noted. The test data plotted on this figure are from the Lewis Research Center, since data from a single test and consequently the same heat flux parameter covers a wider range of wall and bulk temperatures. The conclusions drawn from this figure are:

> The empirical equations represent the test data at local coolant temperatures above 80°R.
>
> The experimental relationship between the local coolant temperature and the local wall temperature for coolant temperatures below 80°R are not adequately predicted by the empirical relationships currently employed.

Present efforts are, therefore, being directed toward determining an empirical liquid-side coefficient C_L (similar to gas-side coefficients C_g), which will result in a better prediction of the wall temperature at coolant temperatures below 80°R.

The 130-gallon high-pressure cryogenic heat-transfer facility has been modified to aid in single-tube liquid-side studies to investigate fluid



SYMBOL	$\frac{(Q/A)\ D^{0.8}}{G^{0.8}}$	TEST NO.
○	0.51 - 0.65	667
□	0.88 - 1.10	708
△	1.10 - 1.33	881

(LEWIS RESEARCH CENTER UNPUBLISHED TEST DATA)

Figure 27

Variation of Tube Wall Temperature with Coolant Temperature for Constant Heat-Flux Parameter friction and heat transfer. The full-scale U-Tube will be tested upon availability of this heat transfer facility.

D. NRX TEST ANALYSIS

The NRX-A3 EP IV test shut-down transient has been subjected to considerable analysis to determine whether tube wall temperatures reached a critical level at any time during the emergency shutdown. Various transient cases for different ratios of nozzle-to-coolant flow were considered. It was determined that temperatures did not reach a dangerous level at any time during the run.

E. SINGLE FULL-SCALE NOZZLE TUBE ASSEMBLIES

The full-scale single U-tube test section (for use in determining pressure-drop characteristics under adiabatic and asymmetrically-heated conditions0 has been welded and the copper cladding is being electroformed on the crown portion of the tube. The copper coating will be resistance heated to provide a low flux asymmetric heat input to the coolant. A test section enclosure, which can be evacuated, has been prepared for use with this test section. This enclosure is the outer jacket of a surplus double-walled cryogenic vessel, with the instrumentation lines, and electrical bus-bar feed-through built into the end closure. See Figure 28.

A nigh-speed sequential-sampling valve (Model 48L Scanivalve), which was designed for rocket test operations, has been serviced for use in making the pressure profile measurements. This unit utilizes a flush diaphragm pressure pickup and will sample 48 pressure per revolution.

The full-scale U-tube tests will be conducted in Sacramento at the LRO heat transfer facility.

F. DIRECT MEASUREMENT OF NOZZLE-TUBE WALL TEMPERATURE

The four prototype radiometers (P/N 1114230) have undergone checkout tests prior to installation on S/N 021 nozzle for chemical simulation

Figure 28

Full-Scale Single U-Tube Test Section

testing. The environmental tests such as pressure-temperature cycling have been completed and each unit has been vibrated in two attitudes: along the optical axis and perpendicular to the optical axis. Each radiometer was vibrated at 1 g input over the frequency range of 30 to 1500 cps for a total duration of two minutes. The black-body calibration of each unit and secondary calibration with the quasi gray-body heater tube through flowing cryogenic hydrogen has been completed. Difficulties during initial cryogenic calibrations have been attributed to the presence of absorbed moisture and condensable gases on the cold window. The test procedure has been revised to minimize the loss of signal attributed to this condensation. The radiometers are now ready for installation on the S/N 021 nozzle.

G. STEADY-STATE AND TRANSIENT TWO-PHASE FLOW ANALYSIS OF FULL-SCALE NOZZLE COOL-DOWN

As a result of the inability to reproduce analytically the characteristic frequencies and amplitudes of the pressure fluctuations obtained from the full-scale aluminum jacket-tube nozzle, it is planned to prepare a preliminary data presentation report restricted to the presentation of those measured parameters most accurate and pertinent to current analytical and experimental cool-down work.

1.4.7 NERVA NOZZLE DEVELOPMENT PROGRAM

A. DOCUMENTATION

A test plan, RN-TM-0206, was prepared during the report period for acceptance testing of the NRX/EST nozzle. This plan has been revised and is being reissued as Test Plan RN-TP-0001.

Test specification RN-DR-0061 has been prepared to detail specific test conditions and requirements for the various types of nozzle tests to be performed. This specification will be distributed during the next report period.

Specification AGC-90053, Nozzle, Liquid Hydrogen Cooled, for Hot Bleed Nuclear Reactor, Engine System Test, for the nozzle to be used on NRX/EST, was released during this report period.

B. OPERATING MAPS

1. NRX/EST Operating Maps

In expectation of the NRX/EST tests to begin later this year, heat-transfer and stress analyses have been started on the nozzle. The objective is to define the operating margin of safety for the nozzle and hot-bleed port at all possible power conditions.

The effort consists of three separate parts which must follow in the order noted:

Systems analysis to define fluid flows, temperatures, and pressures within the system at all conditions of power.

Nozzle and hot-bleed-port heat-transfer analysis to define limiting tube and jacket temperatures during operation.

Structural analysis to define the stress picture at the various power levels considered.

The ultimate result will be operating maps for the nozzle and hot-bleed-port covering all anticipated power conditions. The maps will be in terms of wall temperature, hot-gas temperature, chamber pressure, reactor power, and flow rates,with an upper limit line superimposed. To date, work on this program has been directed toward a thorough analysis of the data obtained in the NRX-A2 and NRX-A3 tests. In this way, the most possible benefit will be obtained from past experience.

2. Extension of NRX-A Operating Map

The NRX-A nozzle operating map is currently being extended to cover power levels up to 200% of nominal. This is being done in support of the considered uprating of power for the NRX-A6 test. The end result of thi effort will be useful in defining the operating limit of the NRX-A nozzle.

C. BRAZE ALLOY TEMPERATURE MEASUREMENTS

For the first time in the program, experimental wall temperatures have been obtained on the coolant tubes during a nuclear test. Braze alloys had been deposited on S/N 022 nozzle prior to the NRX-A3 tests recently completed. On-site remote inspection of the deposits after the test revealed the wall temperature profile in the nozzle, with the exception of the throat region.

The throat temperature data are not available because of inadequate access to the nozzle throat. Re-examination of this zone will be made as soon as improving the accessibility has been completed.

This information will be utilized in future analyses on NRX/EST and XE nozzle analytical work.

Plans to deposit alloys in NRX-A4 and EST nozzles are being finalized. Results from the NRX-A3 tests are being utilized to select the proper alloys for their optimum positions.

D. NOZZLES

1. Nozzle Design Activities

The design of the bolt coolant system was modified to carry 8 lb/sec of hydrogen by enlarging the throat of the venturis in the bolt coolant supply lines, and adding bypass holes in the main nozzle flange.

The bolt coolant system in the main flange was also modified to provide more effective cooling to compensate for the increased radiation heating caused by the addition of the vertical shield. The bolt coolant now flows into an exterior manifold on the convergent portion of the nozzle near the main flange. From here the flow goes into holes drilled parallel to the axis of the nozzle into the center of the flange. At this point, the flow divides. A portion of it goes through the bypass holes directly into the pressure vessel cavity, while the remainder flows through holes drilled radially in the main flange to an exterior manifold on the O.D. of the flange and then back into the bolt holes. For flow requirements of less than 8 lb/sec, restrictors will be added. This modification has been made to provide the additional fuel flow requirements of NRX/EST for turbine drive fluid without further increases in nozzle pressure drop.

Design modifications have also been made to incorporate the latest NRX/EST instrumentation requirements. The nozzle design now has eight thermocouple pass-throughs.

Fabrication tolerance problems on nozzles S/N 021 and 026 have precluded machining the bleed-port-hole diameter to the drawing dimension. An undersize condition on the order of .030" on the diameter was accepted in lieu of machining further and cutting the coolant passage wall, which would reduce the tube side wall and end-cap thickness below drawing tolerances. A design change is in process which, in effect, duplicates the action taken to correct the condition on S/N 021 and 026.

2. Detailed Status of Nozzles

S/N 022, NRX-A3 Nozzle, Post-Test Inspection

A detailed inspection of S/N 022 nozzle was made shortly after the test series completion. In spite of some minor heat markings, it is concluded that the nozzle is capable of further operation.

The heat marks mentioned which were noticed in the region of the core support flange, were evenly spaced every 30°, with 12 total areas counted. Each area covered 5 to 7 tubes and extended from the core support flange to a maximum of 2 inches into the chamber. From the description given, it can be assumed that the heat marks are related to the 12 control rods in the core which are located exactly between each of the 12 heated areas.

Two coolant tubes were also slightly discolored in the cylindrical and convergent portion of the chamber. However, they appear to be intact with no other effects visible.

S/N 024, NRX-A5 Nozzle

Brazing of the coolant tubes to the jacket had just been completed at the beginning of April. Weld installation of components and final machining were completed early in May, and hydrotesting was begun. During leak test, 8 leaks were found and repaired: 7 in the end-cap weldments and 1 at a thermocouple pass-through.

During the flushing operation, foreign particles entered the nozzle from Hydro-Lab facility lines. Back flushing and probing operations were performed to remove the obstructions. Individual flow test of each coolant channel has indicated that all obstructions have been removed, except for one tube which is questionable. It will be probed to clear it of any foreign material.

S/N 026, NRX/EST Nozzle

By the end of April, the coolant entrance and exit holes had been drilled, the bleed port boss I.D. and O.D. contoured, and 26 coolant entrance and exit slots at the bleed port manifold machined, and the bleed-port sleeve welded. It was then shipped for tube installation and brazing, the brazing being accomplished by the middle of May. Weld installation of components and final machining were completed late in June. The unit is now ready for final hydrotesting.

S/N 027, NRX/EST Backup Nozzle

Contour machining of the O.D. of this nozzle was in progress at the beginning of April. Late in April, the O.D. and I.D. contour machining was completed and grooving commenced. The grooving and scalloping of the nozzle were completed by the end of May. The drilling of the coolant entrance and exit holes and the contour machining of the bleed port boss I.D. and O.D. were completed late in June. The 26 coolant entrance and exit slots at the hot bleed port manifold are presently being machined.

S/N 028, NRX and XE U-Tube Configuration Nozzles

Rough contouring of this nozzle was in progress at the beginning of April. The forging in the area of the bleed-port boss did not have enough metal to make the finish dimension, so extra material in the form of a ring was welded onto it. The final contouring of the I.D. and O.D. was completed early in May. The grooving of the nozzle was completed early in June. The coolant entrance and exit holes were drilled and the bleed port boss I.D. and O.D. contours were machined. The nozzle is presently ready for the machining of the 26 entrance and exit slots around the bleed port manifold.

S/N 029-032 NRX-A6, XE-1, XE-2 and XE-3 Nozzles

The forging for nozzle S/N 029 has arrived at Aerojet, However, no fabrication has begun on this unit. The forgings for nozzle S/N's 0030 and 0031 have been shipped from the vendor's plant. The spare nozzle forging (S/N 0032) has been ordered.

E. BLEED PORTS

S/N 021 Nozzle

The bleed-port assembly with a Hastelloy sleeve for development testing with nozzle S/N 021, has been received from the vendor and reworked to fit the undersize bleed port bore of that nozzle. This was accomplished by removal and replacement of the outer sleeve of the port with one of smaller inside diameter to provide a resultant wall thickness after machining consistent with drawing requirements. This port has bypass holes sized for operation at a P of 90 psi (from bleed port inlet to Pc) for a design diluent flow of 5.6 lbs/sec at 240°R. This modification has been incorporated as a drawing change, and will occur in bleed ports for all future nozzles, including S/N 026 (NRX/EST prime).

S/N 021 and NRX/EST Backup

Two back-up bleed port assemblies for S/N 021 and NRX/EST have been received from the vendor. These ports have stainless steel sleeves and Inconel 718 flanges.

CFDTS Nozzle

The bolt-on bleed port for CFDTS has been upgraded to more closely duplicate the NRX/EST model, i.e., the bypass holes have been sized and eloxed in the port, so that the port will have the same pressure drop as the NRX/EST bleed port assembly.

NRX/EST Nozzle

Two all-Hastelloy bleed-port assemblies for NRX/EST will be completed early during the month of July. This port is identical to the one for S/N 021 nozzle except for flange material (the S/N 021 port has an Inconel 18 flange). One of these ports will be held as backup for NRX/EST. One additional bleed port with Hastelloy body and Type 347 stainless steel sleeve, will be available during the month of July as backup to the units with Hastelloy sleeves. This will assure port availability for NRX/EST in the event an unpredictable mode-of-failure develops because of the use of Hastelloy as the sleeve material.

F. THRUST CHAMBER VALVES

1. Failure Analysis

The concept of linking the thrust chamber valves together was studied. It was expected that by linking the valves mechanically, several potential modes of failure could be eliminated from the chemical tests. On completion of the studies, it was decided to abandon the concept for several reasons:

A system which was mechanically simple would not produce the desired valve phasing.

A system which would produce the desired valve phasing was mechanically cumbersome and may be less reliable than the separately actuated valves.

The design was made more difficult by the restriction that phasing must be similar to the current phasing obtained with separately actuated valves. It was felt that to leave a proven start transient and move into an area in which there was no experience, would be a risk not commensurate with the advantages obtained.

To improve the reliability of the separately actuated valves currently used, two steps have been taken:

New thrust-chamber valves will be employed to the extent of their availability. These valves, built to the quality standards and controls of deliverable hardware, will have inherently higher reliability than the development components used to date.

Test records of the existing valves have been reviewed and those with a long service life are being retired from use. The remaining units are being reworked completely, with a proof and a leak check being performed which is identical to that performed on the new thrust-chamber valves.

2. Detailed Status of Thrust Chamber Valves

Fuel Valves

Five new 4-in. valves are to be fabricated. Two of them, S/N's 546 and 593, are now complete. The others range between 20 and 70% completed.

Oxidizer Valves

A total of five 5 in. oxidizer valves are to be fabricated, no completed units having yet been released. Two of them are 70% complete, but are held up for drawing revisions. The remainder range up to 70% complete.

Dump Valves

A total of two of the 5-in. fuel dump valves are to be completed. One valve is now 90% complete and the other, 60% complete.

G. TEST SUPPORT EQUIPMENT

1. Injectors

Injector S/N 1482 with copper face plates and KAMT 51-1 pattern was tested satisfactorily three times for a total duration of 172.2 sec without significant damage. The last test was for 100.4 sec duration at nozzle simulation conditions, demonstrating the adequacy of this type of injector for nozzle life equivalence tests. The only injector damage during this series of tests was the eroding off on one face coolant tube.

Based upon the successful experience with the copper face plate pattern, KAMT 51-1, further development of the injector has been terminated. Three units, with the KAMT 51-1 pattern, are available for nozzle testing.

One steel face injector, pattern KAMT 51-2, is available for backup to these, pattern has not been qualified for use, however, and no additional injectors will be built or modified to this configuration.

The previous NERVA Progress Letter reported the individual status of each injector by serial number and its condition.

2. Adapters

All units, with the exception of the following three, are in long term storage with no intent for future use. The previous NERVA Progress Letter reported on the individual status of each adapter.

S/N 004N - This adapter was removed from S/N 007 TCA after the 1.2-08-NNJ test series. External leakage had been noted from the seal between the manifold and the adapter core. Rework requires a new seal, which has been ordered.

S/N 005N - This unit is available, but has been inactive throughout the report period.

S/N 006N - This unit required some minor rework when it was determined that the forward flange had shrunk due to welding on the torus. Seal grooves had to be reworked to allow proper seal installation. It has been installed on S/N 021 nozzle test assembly.

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1.5 ENGINE CONTROLS

1.5.1 CONTROL SYSTEM ANALYSIS

A. CFDTS

The CFDTS tests have been analyzed to determine their effects on the design of the XE-1 Engine and the NRX/EST Control System design. Data from the tests indicate that the turbopump will accelerate with a very small pressure drop across the turbine. It also indicates that the two-phase oscillations which occur immediately after opening the propellant discharge valve do not cause large chamber pressure oscillations. This makes it feasible to close the pressure loop at the initiation of boot-strap and to allow the pressure error to bring the TPCV open until it reduces the pressure error to zero and achieves stable chamber pressure control.

Integration of these test data with the control design for NRX/EST has resulted in the use of the pressure loop closure at very low pressures, and has eliminated the problem of independent TPCV scheduling. This integration also permits a proper evaluation of the requirements for bringing up reactor power with relation to the scheduling of the chamber pressure.

B. MALFUNCTION ANALYSIS

An evaluation of the flow malfunction which occurred on NRX A3 testing has been conducted, and the results incorporated in the design of the emergency systems for NRX/EST. A report on this study will be incorporated in the NRX A3 Data Analysis Report to be published by Sub-subtask 1.8.6.

C. POST-TEST ANALYSIS

The resul of the NRX A2 and A3 tests have been evaluated in terms of the performance of the flux and temperature loops to determine their use in the NRX/EST Control System. These loops in general perform quite well during these tests. Insufficient trans.er function data and cross-correlation data have as yet been provided to adequately determine the exact dynamic characteristics of these loops.

D. XE-1 ENGINE, AND NRX-A3 AND NRX-A4/EST CONTROL SYSTEM ANALYSIS

The primary effort herein was to determine the requirements for the NRX/EST Control System. The Control System at this time is fundamentally the same as was originally specified for the E-Engine, with the exception that the NRX/EST possesses an independent power-demand profile which was not included in the E-Engine design. This power-demand profile is redundant with the temperature-demand profile and one has to dominate the other at all times. Since the temperature system can only cause a +15% and a -50% power demand, it is basically a trim system, and the reactor power demand dominates the control system. The exact compensations and gains to be used for the NRX/EST are still being evaluated, but will not differ significantly from those used in the E-Engine studies.

E. NRX-A3 AND -A4 REACTORS AND NRX/EST DYNAMIC CONTROL PERFORMANCE ANALYSIS

The dynamic control performance including the facility control of the NRX/EST was the primary effort during this period. A number of malfunction runs were completed, and the affects of various limiter actions and safety systems on the engine were evaluated. At the close of the period, runs were being made which included the major override systems; i.e., the pressure-error override, the T-26 override, and the power override. These runs will include the various SCRAM and flow shut-down chain features and the ability of the PCV 41 emergency system to maintain engine integrity. A report will be issued during the month of August concerning this work.

F. ANALYSIS OF TSCS REQUIREMENTS

Technical performance requirements for TSCS were a continuing effort. The results from the control and facilities analysis are being continually supplied to the TSCS Project. A detailed facility simulation of ETS-1 is being conducted to provide tie-in capability with the TSCS mock-up program.

1.5.2 CONTROL ACTUATORS

The proof testing of the TPCV actuators has been a continuing effort. Approximately 120 hours of test time have been accumulated on four actuators. During this testing, these have failed:

The carbon end plates on S/N 012 actuator failed after approximately 40 hours of testing. The actuator was refurbished and was again performance tested to verify its capability. There is no previous history of this type of failure and the cause of failure was not determined, but is believed to have been caused by foreign particles in the gas supply.

During the cryogenic testing of the Diluent Control Valve (DCV), a dynamic shaft seal failed. This seal had a Rene' 41 bellows which was not intended for low-temperature operation (this material is now being replaced with Inconel X). The seal failed at 400 psi with liquid hydrogen passing through the valve. Metallurgical investigation of the bellows failure is being conducted.

Another dynamic shaft seal failed; however, this was on actuator S/N 006, and was of an obsolete metal-to-metal type that was known to have limited capability.

A third shaft seal failure was associated with the final performance testing of the NT-D1 model actuator prior to shipment from Bendix. The shaft seal failed when the carbon insert fractured in several places. Review of this seal design showed that it had a major deficiency that will be corrected by a design change. This failure caused the delivery of the actuators to be late.

During the reporting period modifications were made to the actuation subsystems. One of the changes was to re-install one cam-operated switch on the output shaft of the actuator in such a manner that the switch is closed at one point, thus allowing positive indication of the proper quadrant of operation. Another change was the establishment of limits to the command input to the magnetic amplifier. These limits prevent the application of excessively low or high command signals to the actuator and thus eliminate the motorizing problem. A rapid closing switch was also added to allow the rapid application of shut-down signal to the actuator.

In addition to the proof testing of the actuators, beneficial experience was gained by using various actuators for the development testing of the TPCV and DCV. These tests accounted for over 50 hours running time, some of which were under expected engine environments except for radiation. In one of the tests, the TPCV actuator and valve were used as the pressure controller bypass valve in a hot valve test. In the other test, the TPCV Actuator operated a valve through which liquid hydrogen was being circulated.

1.5.3 ELECTRONICS DEVELOPMENT

A. CONTROL AND SIGNAL AMPLIFIERS FOR XE-1 ENGINE AND NRX/EST

Changes in design philosophy reflecting ground test concepts of flexibility and component standardization have resulted in the utilization of standard operational and signal conditioning amplifiers. Preliminary transfer function requirements for the XE-1 control amplifiers have been developed. Primary electrical characteristics for XE-1 signal and control amplifiers have been determined.

NRX/EST control and signal amplifiers are the standard type amplifiers currently used in Test Cell "A". Control amplifier gains and compensations have been specified in the NRX/EST control system design package.

Power requirements have been estimated for XE-1 engine control and definitive specifications are currently being developed and coordinated with the reactor control subsystem designers.

Design and fabrication of the breadboard electronics for the engine programmer and engine controls was completed. Tests are currently being conducted in conjunction with the TSCS mockup (see Item C(2)). Design of the lab model engine programmer electronics has been initiated.

The CFDTS sequencer was fabricated and initial CFDTS tests have been successfully run.

Development tests have been conducted on various electronic components for XE-1 controls. One electronic subsystem developed by AGC is an improved subpower controller which is being implemented by WANL for XE-1 use. Another electronic subsystem developed by AGC for potential XE-1 use is an improved automatic reactor start-up system which is currently under study for test in NRX/A5.

Hardware tie-in studies using the breadboard engine programmer and controls in conjunction with the reactor control subsystem breadboard and TSCS mock-up are currently in progress.

1.5.4 HARNESSES & CONNECTORS

A preliminary point-to-point wiring diagram was previously completed, but the XE-1 Engine new requirements fo. core temperature measurements were submitted to project engineering this quarter.

Efforts on harness and connectors for the XE-1 engine control system item have been confined to the selection and evaluation of connectors and cables for the XE engine system. This work has been consolidated with the instrumentation effort to reduce duplication of work.

1.5.6 MASTER PROGRAMMER

The design of the laboratory model XE-1 engine programmer has been initiated based on the breadboard design, and is being fabricated. Design effort will continue, utilizing the results of the breadboard tie-in, CFDTS, and NRX/EST tests. Functional tests will be conducted during the first quarter of CY 66.

The XE-1 engine programmer breadboard has been tied in with the reactor control subsystem, TSCS mockup, and analog computer, and is currently being tested. Redesign of breadboard components to make them compatible with operational and interface requirements of the TSCS and engine-programmer/controls has been accomplished. A report on the required modifications will be issued to insure that these requirements are reflected in the deliverable equipment.

Evaluation of the TCA for NRX/EST compatibility has been completed. The NRX/EST Engine Control System Design Package has been issued. This package defines the system modifications to TCA required to run the engine system tests.

1.8 SYSTEMS ANALYSIS

1.8.1 NON-NUCLEAR SYSTEMS ANALYSIS

A. BLOCK I TEST RESULTS, CFDTS

1. Engine Start-up Information for Wet Pump

The most significant conclusion to be inferred from the wet pump start-up runs is that engine boot-strap on NRX/EST and XE-engines can be achieved without major problems. [Boot-strap is defined to be the ability of the engine (closed-loop hot-bleed cycle) to start and stabilize at a power level within the operating regime.] From the CFDTS test, it is projected that the requirements for minimum tank pressure (to boot-strap the NRX/EST, XE, and future engines) are determined by the pump NPSP requirement and the suction line losses.

The Block I tests provided a relationship between engine (turbine) speed and tank pressure (Figure 29) for 14-psia turbine and nozzle back pressure. An increase in tank pressure from 50 to 60 psia nearly doubles maximum turbopump speed and multiplies the pump head rise by 3-1/2. However, increasing the tank pressure from 70 to 90 psia increases speed only 12%. The initial acceleration rates of the engine are reasonable for NRX/EST operation. Speed peaks in about 10 seconds for a 90-psia tank pressure and 40 seconds for 50 psia tank pressure. This provides a measure of the time available to bring the reactor to power for the engine startup.

The turbopump begins to rotate within a second of the opening of the Propellant Discharge Valve (PDV) and Turbine Power Control Valve (TPCV). This lag of less than 1-second is achieved with a chamber pressure rise of 3 psia or less. The important conclusion is that the pump will begin to accelerate at very low flow rates. The Aerojet turbopump does not appear to windmill during the chill-down operation prior to opening the TPCV.

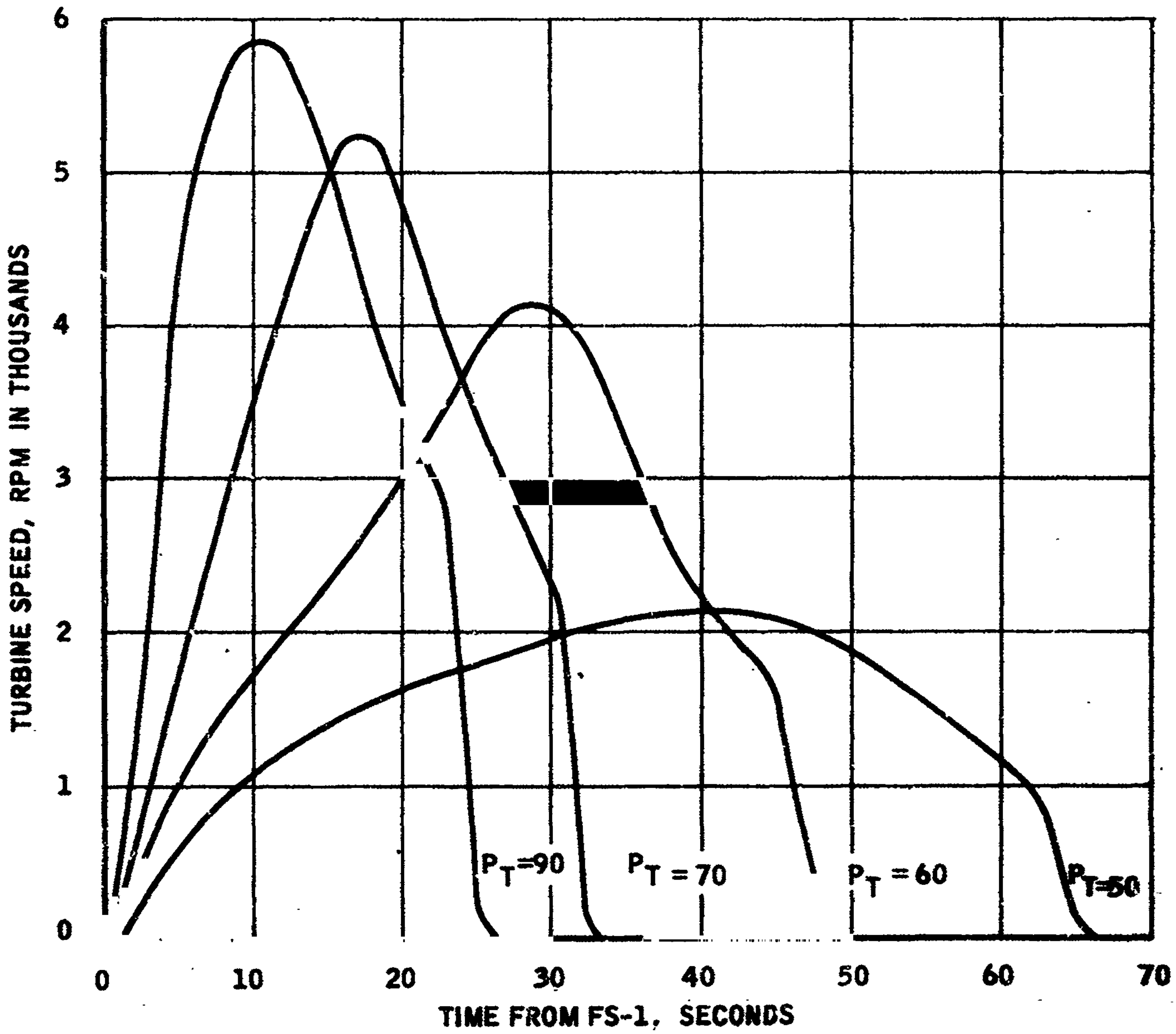


Figure 29

CFDTS Wet Pump Start-up Tests

Turbine RPM as Function of Time

Positive pump head rise in the system was investigated. The runs indicate positive head rise is established between 500 and 800 rpm. The flow oscillations at lower speeds make positive correlations of performance difficult.

The pressure drop through the pump at zero speed was determined. Flows ranged between 6.9 to 12.3 lb/sec depending on the tank pressure. The pressure drops ranged between 2.8 and 7.8 psia across the pump at zero speed.

The loss coefficient for the pump was computed by

$$P = \frac{K W^2}{A^2 \rho}$$

where

ΔP = pressure drop across the pump, psia
K - loss coefficient
W = flow rate, lb/sec
ρ = density, lb/ft^3
A = flow area, in^2

A value of $\frac{K}{A^2} = 2129 \pm 106$ resulted.

The maximum acceleration for the turbopump was 900 rpm/sec. This was experienced with the 90-psia tank pressure.

Figure 30 summarizes the nominal performance of each component at peak speeds. Chamber pressures varied between 19.8 for a 50 psia tank pressure and 55.2 for a 90 psia tank pressure. Flow rates at achieved maximum TPA speeds varied between 8.7 and 24 lb/sec. The apparently large increase in performance caused a change from a 50 to a 60-psia tank, in which flow rate and chamber pressure increased more than 60%.

2. Chill-down Information for Wet and Dry Pumps

Runs 001 and 002 were chill-down runs. Both were at 70-psia tank pressure and were similar, except that Run 001 was made with a dry pump and 002 with

SYSTEM OPERATING PARAMETERS AT MAXIMUM TURBOPUMP RPM							
		RUN 003 5280 RPM			RUN 004 6935 RPM		
NO.	STATION	FLOW lb/sec	PRESSURE psia	TEMP °R	FLOW lb/sec	PRESSURE psia	TEMP °R
1	TANK OUTLET		70.8	38.2		91.4	39.2
2	PUMP INLET	20.1	68.5	38.4	24.0	87.9	39.1
3	PUMP OUTLET		123.5	39.6		≈156	40.1
4	NOZZLE MANIFOLD INLET			46			48
5	NOZZLE OUTLET		112.2	53		141.4	58
6	REFLECTOR OUTLET		107.6	243		134.7	339
7	SHIELD OUTLET		95.3	321		118.1	383
8	CORE OUTLET		44.2	443		55.2	466
9	NOZZLE CHAMBER		44.2	443		55.2	466
10	DILUENT BLEED INLET	.49	87.7		.58	108.9	
11	DILUENT BLEED OUTLET		74.6	401		93.0	427
12	HOT BLEED		44.2	443		55.2	466
13	MIXING RING INLET		42.1	421		51.2	452
15	TPCV INLET		41.3	427		50.3	453
16	TURBINE INLET	.97	40.2	429	1.12	49.0	453
17	TURBINE OUTLET						
18	TURBINE EXHAUST NOZZLE						
		RUN 005 2180 RPM			RUN 006 4222 RPM		
NO.	STATION	FLOW lb/sec	PRESSURE psia	TEMP °R	FLOW lb/sec	PRESSURE psia	TEMP °R
1	TANK OUTLET		48.9	38.9		58.4	39.7
2	PUMP INLET	8.7	49.2	39.1	13.1	57.6	39.2
3	PUMP OUTLET		58.2	39.9		92.4	40.2
4	NOZZLE MANIFOLD INLET		55.0	45		89.9	46
5	NOZZLE OUTLET		48.9	45		82.7	49
6	REFLECTOR OUTLET		46.1	274		77.1	284
7	SHIELD OUTLET		42.5	314		70.7	310
8	CORE OUTLET		19.8	419		32.4	400
9	NOZZLE CHAMBER		19.8	419		32.4	400
10	DILUENT BLEED INLET	.21	39.1		36	64.8	
11	DILUENT BLEED OUTLET		33.5	405		55.6	394
12	HOT BLEED		19.8	419		32.4	400
13	MIXING RING INLET		19.2	406		31.1	354
15	TPCV INLET		19.1	423		30.5	413
16	TURBINE INLET	.29	18.8	4[illegible]	.67	29.8	416
17	TURBINE OUTLET						
18	TURBINE EXHAUST NOZZLE						

Figure 30

CFDTS Wet Pump Start-up Tests
System operating Parameters
at Maximum Turbopump RPM

a wet pump. The differences between the system operation parameters at these two conditions were much greater than had been previously anticipated. It was expected that the dry pump would add only a negligible amount of thermal energy to the gas and therefore would have little effect on the system operation. It appears that a sufficient amount of the liquid hydrogen vaporized in the pump, increasing flow resistance and lowering the flow through the system significantly. Figure 31 is a plot of the system flow rate and the chamber pressure and temperature for the two chill-down runs. As can be seen, the flow rate for Run 002 is over 40% higher than the flow rate for Run 001 at 2.5 sec after the test start and remains considerably higher for the duration of the run. The result of this is to cause the chamber temperature to decrease more rapidly in the wet-pump run.

The data were examined for flow asymmetries during the chill-down. These asymmetries (variation in flow rates between parallel flow channels) had been observed in NRX-A1 and -A2 testing during two-phase flow in the component. The same type of flow asymmetries appear to be present in CFDTS. Closer examination will be required to verify that they are also correlated with two-phase flow. However, flow streaming does not appear to occur between major components; the plenums act to eliminate any adverse effects from flow asymmetries.

3. Chill-down Information During Wet Pump Start

Examination of the data of the material temperatures of the TPA inlet line shows that for all runs the inlet line did not cool as fast as the rest of the system. To obtain a rough estimate of the hydrogen heat transfer coefficients during chill-down, calculations of the average heat-transfer coefficient were made. The computed heat-transfer coefficient agrees with one derived by Bromley for film boiling. The film boiling appears likely in a downward flow of a cold fluid through a hot pipe. This coefficient is considerably smaller than one expects from liquid, vapor, two-phase, or sub-cooled nucleate boiling.

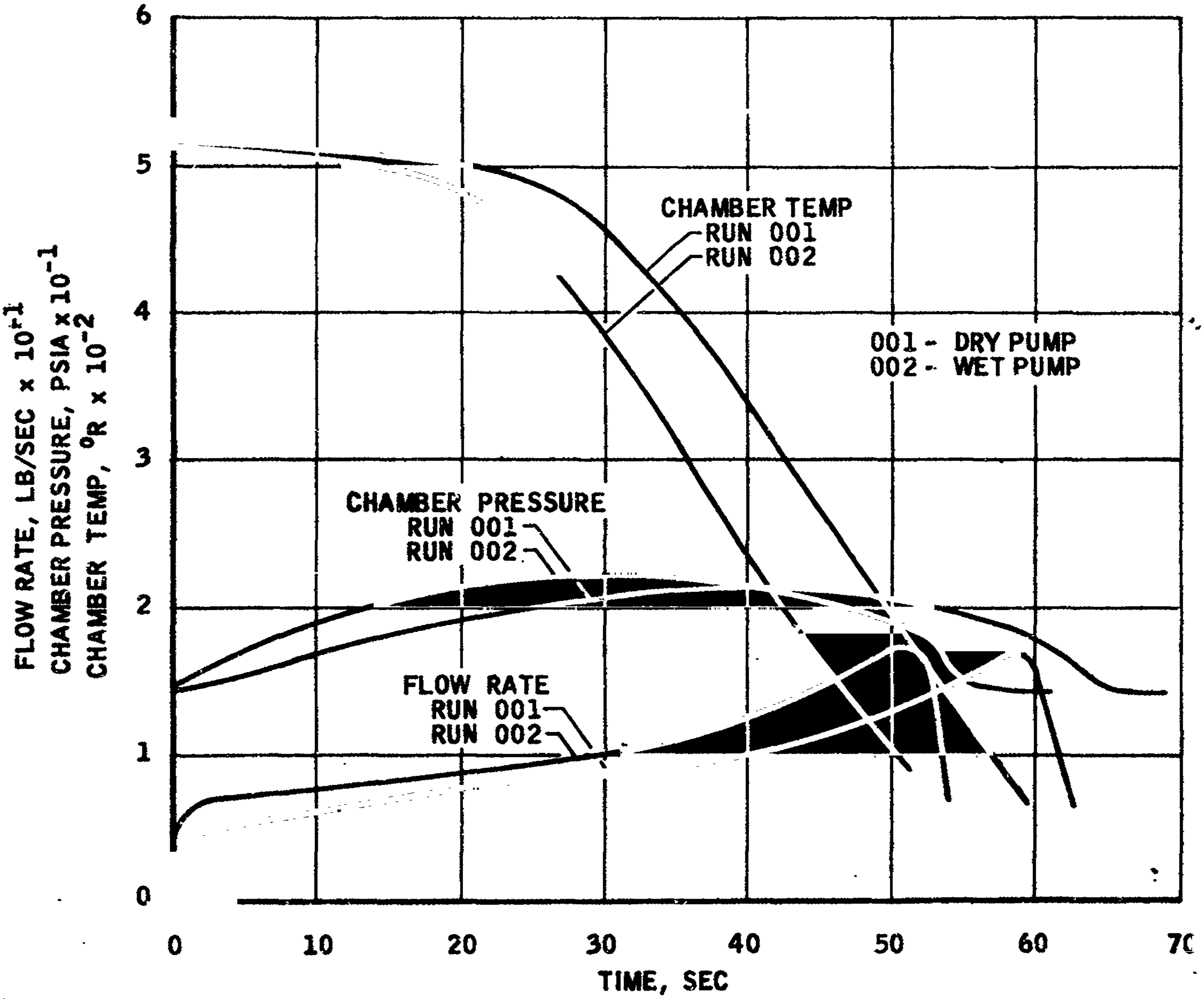


Figure 31

CFDTS Chill-Down Tests

Flow Parameters as Function of Time

One of the significant observations that can be made from the CFDTS data is that the TPA inlet line does not cool as fast as the turbopump housing. For example, at FS-1, the temperature of the turbopump housing is less than 10°R away from saturated liquid temperature, whereas the temperature of some sections of the inlet line are higher than 350°R. This means that there is less intimate contact between the cold hydrogen and the warm walls, thus giving rise to annular flow (liquid core) and poor heat-transfer coefficients. Downward annular flow resulting in less intimate contact between the cold fluid and warm walls may be one of the reasons for the observed oscillations of low amplitude, as compared with the chill-down analysis.

4. Low Speed Turbopump Data

Data from the CFDTS Block I test, Runs -003 through -006, are being analyzed in order to obtain a clearer definition of the Mark III, Mod 4 TPA at low speeds. These data will be used to improve systems predictions for future CFDTS tests. Previous data were not primarily concerned with this operating region and projections of the low speed range were found to be inadequate when used in the system transient analysis prediction. Test data from Runs 003, 005, and 006 were used to map the pump operation from zero speed to speeds of 5,000 rpm. The limitations of this data are recognized in that the data are for a period of slow transient performance, but the pump was assumed to be at steady-state in the data analysis.

5. Pre-Test Predictions

Pre-test predictions for CFDTS, as expected, were not in good agreement with the system performance. The CFDTS runs in an area where component performance data was admittedly lacking. For instance, for a 70-psia tank pressure wet pump start, it was predicted that a speed of 2000 rpm would be reached. However, the system behavior was much better than anticipated and reached 5280 rpm. CFDTS proved its value to the NRX/EST and XE-engine programs by providing initial engine start-up data.

B. BLOCK II TEST - PERFORMANCE ANALYSIS

The block I tests provided data on wet and dry pump chill-down, and wet pump starts with different tank pressures.

The Block II test will provide the following additional data:

Performance differences using the modified turbine to an NRX/EST configuration.

The effect of a complete chill-down of the suction line before the wet-pump start is initiated.

Data on the performance at NRX/EST back pressures and tank pressure conditions.

An evaluation of the automatic pressure controller performance during initial engine start-up operation.

Data on the effects of reduced tank pressures with minimum back pressures.

Dry pump start information.

A series of analog studies were performed in order to establish a reasonable test program and to provide a preliminary CFDTS pre-test prediction on performance.

1.8.2 NRX SYSTEM ANALYSIS

Major support was provided the NRX-A3 test system both prior to, and during the test. Prior to the test, steady-state mappings of the NRX-A operating region were made and transient analyses of the proposed test ramps performed. In addition, the nozzle conditions were mapped over the entire operating region.

During the test series, major effort was provided in determining the systems performance during the emergency cool-down in EP-4. Preliminary post-test analyses were made to estimate the condition of the engine prior to continuing with EP-5. The SCRAM, as run, resulted in severe environments in two areas - the tie-rods and the nozzle tubes. The potential damage to the nozzle tubes is the result of a possible flow differential across the tubes during the rapid transients shortly after shut-down. The entire period over which this may have occurred is estimated to be only two to three seconds in duration. These three techniques were used to estimate the flow differential during the critical period:

Hand calculations to estimate the average flows in each major engine component; the nozzle tubes, the reflector, the shield, the reactor, and the nozzle throat. The flows in each of the components were estimated using the observed ΔP's and average densities at finite time intervals following the emergency shut-down. Capacitance effects within the engine caused widely varying flows, particularly on the hot and cold side of the nozzle tubes.

Hand calculations were made to estimate the flow which could have entered the nozzle during the critical time period. The assumption was made that the feed lines acted as a blowdown tank process. The factors controlling flow into the nozzle were the feed hydrogen flow which required a finite time for termination; the hydrogen gas in the purge line which began to expand as the nozzle inlet pressure dropped and pushed cold hydrogen into the nozzle from the feed line; and the initial purge pressure.

The Aerojet Transient NRX Digital Computer Program was run using recorded pressures, temperatures, and powers in order to determine engine flows during the transient.

The major discrepancy in the analysis is that the computed flow entering the nozzle by the feed system analysis is less than that shown in the engine system analysis. Part of the problem comes from the feed system analysis which could not account for a pressure surge occurring at 21708.9 seconds. However, based on the extreme results from the analyses, the flow differentials amount to 31-57 lb/sec and 29-46 lb/sec across the nozzle. These differentials are not of large enough magnitude to damage the nozzle.

Techniques were developed to obtain a rapid estimate during testing and DRAGON team operation of total power based on chamber pressure, temperatures and flow, and reactor power, using a nozzle flow map. The absolute value of these measurements should intersect at one point if all measurements were 100% accurate. As seen on Figure 32, they do not intersect at one point, but rather form the cross hatched triangle noted as "A". To further define the area within which the power most likely falls, the 95% confidence bands have been added to each of the observed values. This gives the smaller area, noted as "B" on this figure, an area within which it can be said with 95% confidence the power actually falls. The direct power determination has historically been a poor measurement running low on NRX-A2 and KIWI-B4. If it is discarded, the power can be estimated to be within the small darkly shaded area, noted as "C" on the figure. The DRAGON team selected this area for the official full power estimate. It should be noted that measured chamber thermocouples proved to be a good measure of nozzle conditions.

For the planned power run in EP-4, good agreement was achieved between the Aerojet Transient Program and the test measurements. Pre-test predictions were made based on intended operating conditions of flow and Station 26 thermocouples. Since Station 26 thermocouples did not prove to be a good measure of chamber temperature, a post-test run was made with power and flow as the input quantities. For pressure, agreement was within 2%, which is within the accuracy of the instrumentation.

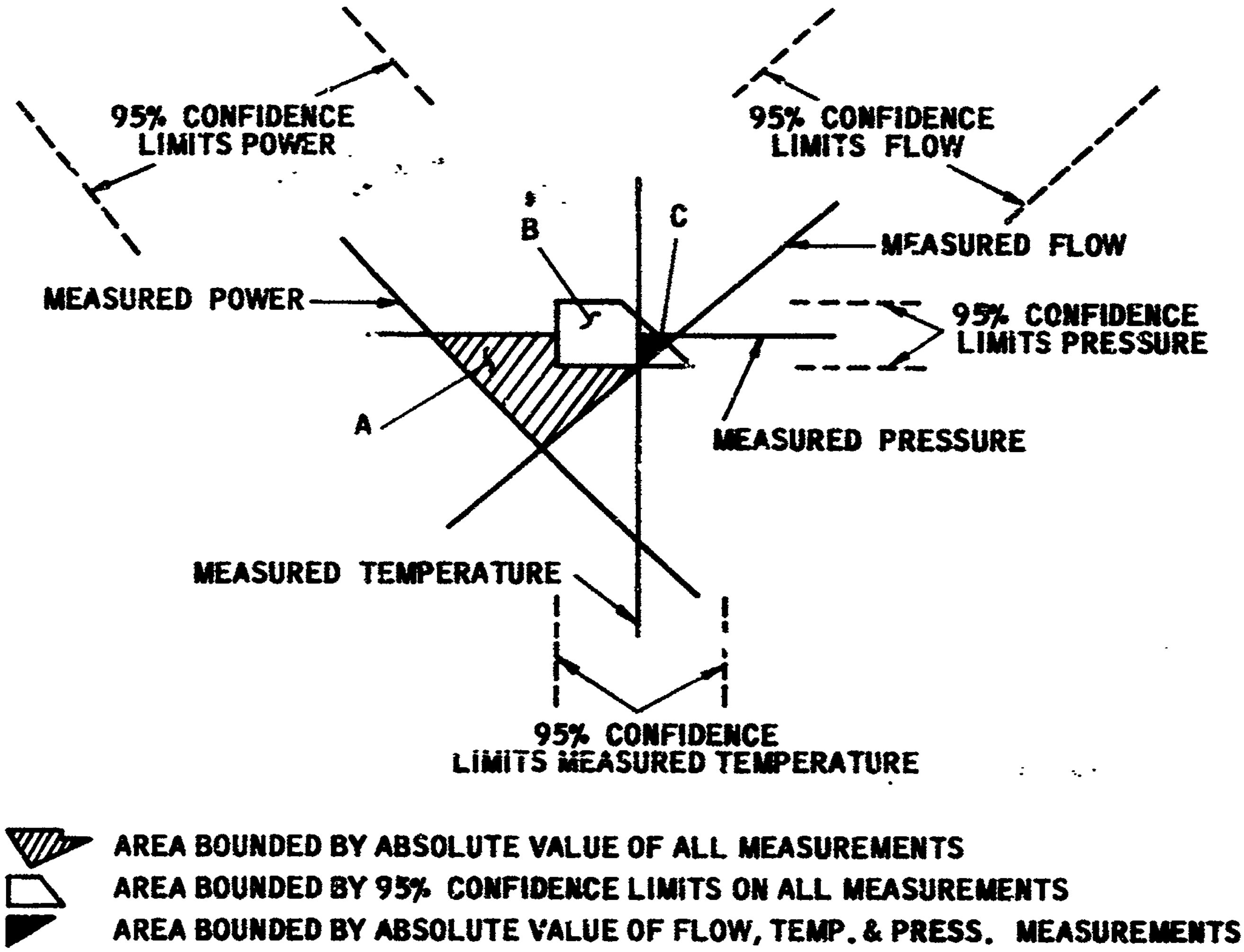


Figure 32

Interrelation of Measured Test Parameters

on Nozzle Flow Map

1.8.3 ENGINE SYSTEMS ANALYSIS

A. NRX/EST

Detailed studies have been made on the NRX/EST system. In order to provide component inlet and outlet conditions under all possible conditions, a steady-state operating map was prepared. Plots of key components, such as the turbopump, turbine, nozzle, and reactor, were prepared. In addition, a constraint map has been prepared to help define the allowable operating limits (Figure 33), and various power holds proposed in the NRX/EST Test Plan have been analyzed.

A proposed bleed line between the TPCV and TBV was analyzed. It was found that the flow to the turbine due to leakage would be reduced in half during reactor only operation.

The turbine inlet line bypass for NRX/EST was analyzed. Various configurations were investigated, with the final configuration being a sonic orifice placed immediately upstream of the bellows section on the bypass stack. The orifice was sized for steady-state operating conditions.

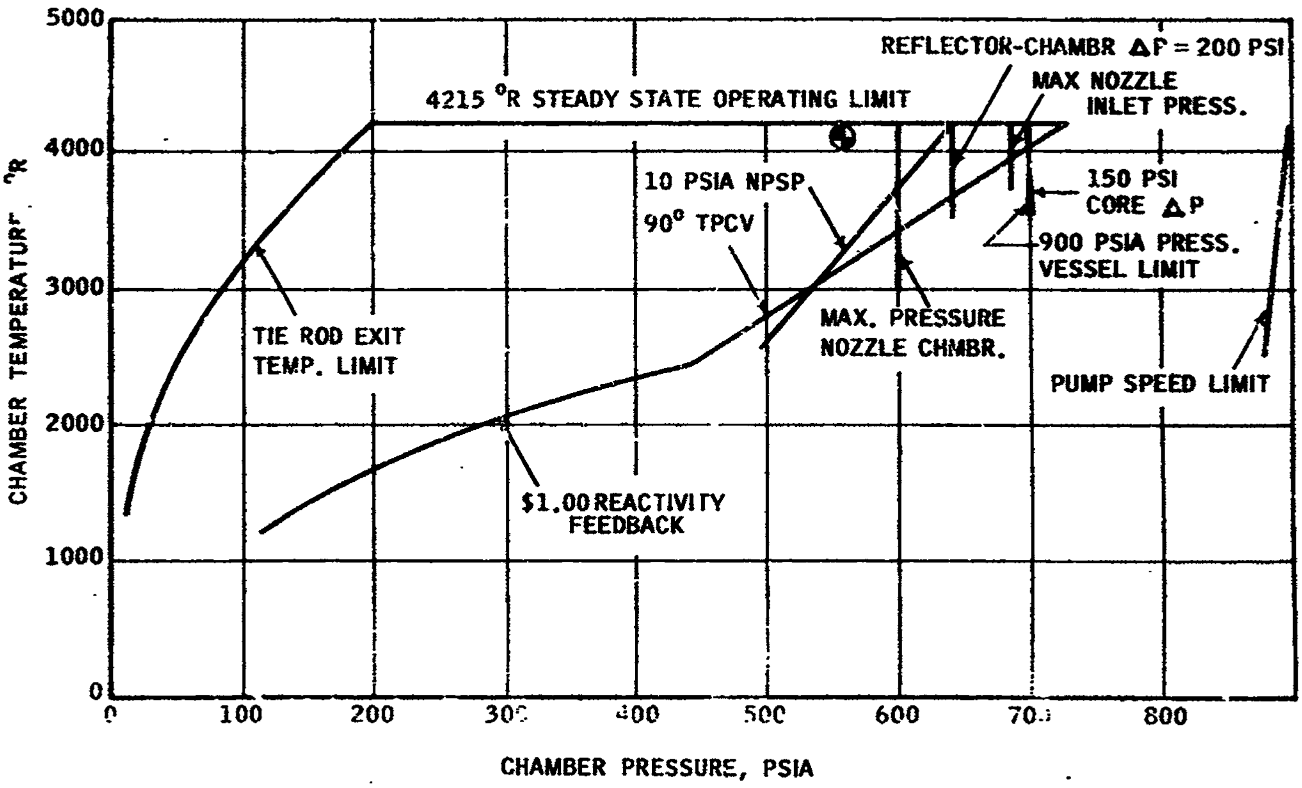
Work was performed on the Pre-Test predictions report for NRX/EST. Emphasis will be on making the document a working tool for people during the test series.

B. XE-ENGINE

A new steady-state operating point was prepared reflecting the latest information from CFDTS and NRX-A3 testing. Revised component test data were included.

An updated constraint map has been prepared reflecting the latest component information, and with revised constraint limits.

For the X-Engine, an emergency cool-down analysis has been performed for a 1225-second run in ETS-1. The run indicated that nitrogen could not be introduced before 1100 seconds after SCRAM and remain within the nitrogen facility constraint. The helium requirement would be greatly increased.



	Constraint	Limit
1.	Feedback Reactivity	$1.00
2.	Nozzle Chamber Temperature	4215°R
3.	Tie-Rod Exit Gas Temperature	1200°R
4.	Nozzle Inlet Pressure	1100 psig
5.	Core Pressure Differential	150 psi
6.	Reflector Inlet/Core Outlet Pressure Differential	200 psi
7.	Engine Pump Suction Pressure	10 psia
8.	Engine Pump Speed	28,000 rpm
9.	Turbine Inlet Temperature	1500°R
10.	Reflector Inlet Pressure (pressure vessel limit)	900 psig
11.	Nozzle Chamber Pressure	585 psig

References:

NRX/EST Test Specification, NJD-2
WANL-TME-840A

Figure 33

NRX/EST Operating Map
Summary Constraints

1.8.4 ADVANCED ENGINE ANALYSIS

The thrust vector control requirements for nuclear rocket engines during the start-up period are of considerable interest when applying NERVA II to a particular mission profile. This is particularly true in the propulsion modular approach, where the modules must be designed so that they can achieve attitude control when used as individual modules or in clusters of three or more. The attitude changes requiring control are largely due to engine start transients and misalignments; stage misalignments and center of gravity changes; stage separation disturbances; and maneuvers in response to commands.

A. NERVA II CONCEPTUAL LAYOUTS

A conceptual design layout of NERVA II incorporating various thrust vector control mechanisms and component orientation was completed and is shown in Figure 34. The ring gimbal concept with the non-nuclear components arranged in the conventional manner is shown as Figure 34A. This configuration features a 13-ft reactor-tank separation distance. The ring gimbal is mounted directly to the pressure vessel head. This gimbal location moves the center of the gimbal mass approximately 80-in. forward and reduces the inertial moment.

Figure 34B shows the 3-point suspension system as applied to the NERVA II. In this system engine loads are absorbed through three suspension points.

The centerbody gimbal is illustrated in Figure 34C. This concept imposes an undue weight penalty because of the longer engine length.

Finally, a close-coupled arrangement of the ring gimbal concept is shown in Figure 34D. Close coupling is achieved by positioning the propellant shutoff valve inside of the propellant tank. The turbopump assembly is mounted directly to the valve thereby reducing the reactor-tank separation distance to approximately 11-ft.

The various thrust vector control concepts are being investigated to evaluate the trade-offs between engine and interstage weight and actuator power requirements. The implications of the close-coupled design on the top shield design will be evaluated by WANL. In addition, thrust modulation for attitude control of clustered engines will be investigated.

(Text continued on page 130)

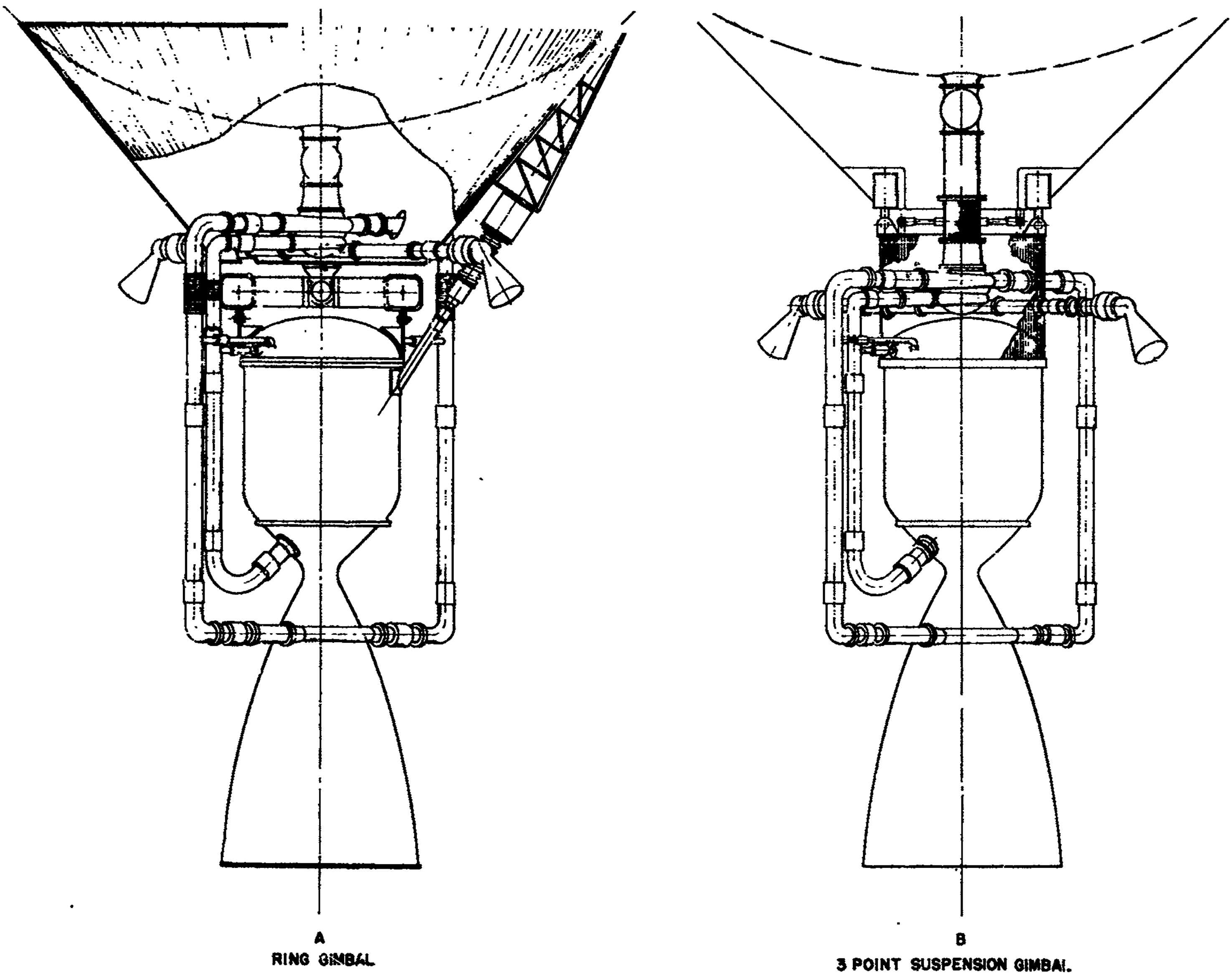
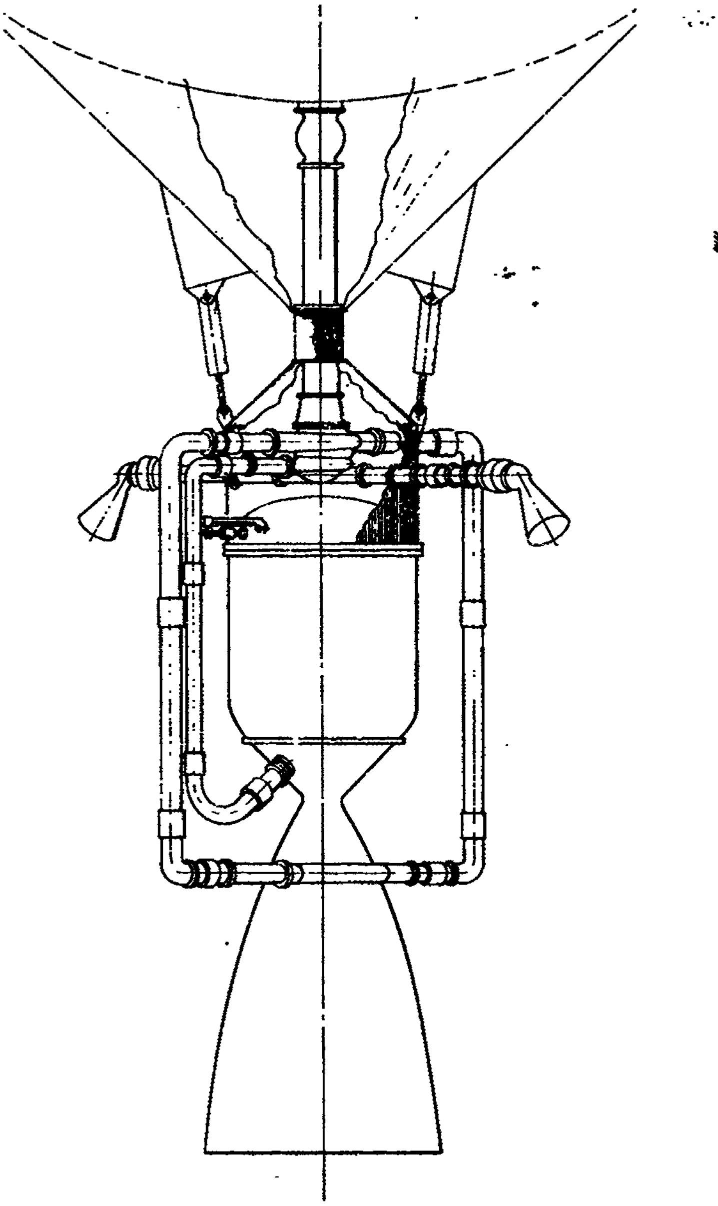


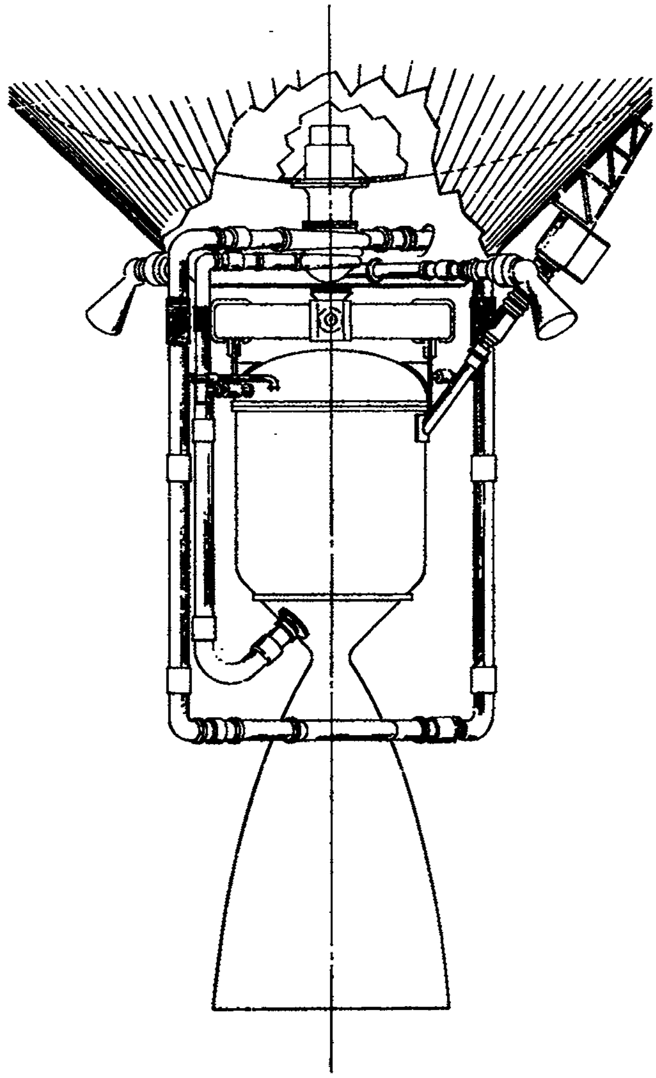
Figure 34 (Sheet 1)

NERVA II

Conceptual Layouts



C
CENTER BODY GIMBAL



D
RING GIMBAL CLOSE COUPLED

Figure 34 (Sheet 2)

NERVA II

Conceptual Layouts

An analysis was initiated to determine the pressure and mass flow rate of the recirculating exhaust gases in the base region between the three cluster triangular arrangement. In addition, the heat-transfer rate to several representative surfaces will be evaluated.

The critical flow cross-sections in the base region were determined and the areas calculated. An existing computer program was modified and run to provide exhaust plume contours for the backflow problem.

From the computer calculations, existing published data on mass flow functions were extrapolated to match the operating conditions of the selected configuration. The equilibrium recirculating mass flow rate and source pressure was established. In addition, several representative target areas have been established to evaluate the heat transfer from the recirculating exhaust gases.

During the next report period the velocities and densities of the recirculating exhaust gases in the vicinity of the selected target areas will be determined. Based on these results the heating rates at the various target areas will be calculated.

B. CONTROLS ANALYSIS - NERVA II

The controls analysis for the single NERVA II was completed during this report period. The control system developed for the XE engine was found to be satisfactory for NERVA II. However, the overall gain of the compensation networks for the temperature and pressure control loops in the XE engine had to be reduced because of the slower dynamics of the NERVA II.

Tie tube coolant flow during power range operation was controlled by an orifice in the tie-tube feed line. The orifice was calibrated to allow a predetermined tie-tube wall temperature at full-power operation. Various transient conditions were investigated to determine the effect of regulating the tie-tube coolant flow with a fixed orifice. This method was shown to be satisfactory for all transients investigated.

Start-up characteristics were examined by bringing the engine model up to full power on three different chamber temperature ramps of 100°, 200°, and 300°R/sec. Satisfactory performance was achieved for all cases.

Engine shut-down was investigated for two temperature-pressure programs. In one case a moderate program of 90°R/sec and 12 psia/sec was analyzed. In the other case a faster program consisting of 175°R/sec and 30 psia/sec was studied. No attempt was made to optimize the shut-down program. Both programs resulted in satisfactory performance.

C. TURBOPUMP STUDY - NERVA II

The study of a single turbopump assembly for NERVA II was initiated to determine a design for optimum hydrodynamic and cavitation performance with minimum weight; for example, pump efficiencies in the range of 80-85%, and a NPSP at the pump inlet of 2 psi (NPSP equal to velocity head). The study will include all known advance design concepts in the areas of centrifugal, mixed, and axial flow pump configurations.

One-dimensional analysis, thus far, has produced a centrifugal design similar to the NERVA I design, i.e., impeller diameter 13.5 inches, and shaft speeds in the 22000-25000 range. Performance predictions similar to the Mark III Mod 4 have been supplied to the engine balance computer program for evaluation. Tests are now scheduled to permit determination of the losses in the housing, which will permit evaluation of advanced design concepts for high efficiency mixed flow and centrifugal pump designs.

A parametric investigation of an axial-flow multistage turbine in terms of performance and weight is being conducted for a given specific work output required by the NERVA II pump speed and power requirements. In this study, the most significant performance parameters are varied over the expected range of interest. Included among these parameters are flow rate, pressure rate, total inlet temperature, nozzle exit angle, and stage number. The analysis assumes one-dimensional flow at mean blade radius, equal work per stage, and equal blade speed, and neglects the reheat effects.

The overall efficiency is based on the total-to-static pressure ratios across the entire turbine and is defined in terms of stage number, total efficiencies of the (n-1) stages, and static efficiency of the last stage. The stage and overall efficiencies are a function of the "Parson's" characteristic number defined as the ratio of the square of the rotor mean blade speed to the specific work output.

This study when completed will allow turbine weight and flow rate to be minimized for NERVA II application. Turbine flow rate reduces the effective rocket specific impulse while weight and efficiency have an effect on the gross-to-pay weight ratios, weight being less significant than efficiency.

1.8.5 NON-NUCLEAR SYSTEMS DATA ANALYSIS

A. ANALYSIS OF CFDTS DATA

Use of the 364 Program for CFDTS data analysis was initiated, and the model was upgraded, based upon NRX-A2 and CFDTS test data. It was found that the heat-transfer coefficients originally used caused discrepancies. Turbopump data from CFDTS tests are being programmed in 364. Good agreement was obtained between measured and calculated conditions for Test Run 2.

Pressure rise across the pump was correlated using the parameters $\Delta P/\dot{W}^2$ and $N/\dot{W}$ for CFDTS Run 3 data. The following correlation was obtained using only data points for which $N/\dot{W}$ was greater than 2 rev./lbm:

$$\Delta P/\dot{W}^2 = -0.047 + 1.47 \times 10^{-4}\, N/\dot{W} + 1.97 \times 10^{-6}\, (N/\dot{W})^2$$

where

ΔP = pressure rise in psia
$\dot{W}$ = flow rate in lbm/sec
N = rotational speed in rpm

A correlation coefficient of 0.987 was obtained; however, the confidence limits of the regression coefficients are quite wide.

B. 364 PROGRAM

The program was modified to have choked flow at the core inlet orifices and checked against NRX-A2 chill-down data. The core inlet pressure agreed within 2 psi (6%) and flow rates within 0.4 lb/sec (9%) of data values during the 55-second run. Work is proceeding to match CFDTS chill-down performance. Low speed pump performance equations have been added. Multiple choking conditions are beind added to the system, and logic changes are being made to obtain convergence. An NRX engine model was modified to include a 2-pass tie-rod flow configuration.

1.8.6 NRX SYSTEMS DATA ANALYSIS

A. NRX-A2 REPORT

REON Report RN-S-0208, Data Analysis Report of NRX-A2 Tests, Volumes I and II, dated May 1965, was published.

B. NRX-A DATA ANALYSIS

The data analysis report for NRX-A3 is being prepared. The S/N 022 nozzle used in the NRX-A3 test series has been incorporated into the 364 Program model. The 364 Program input (which will be used to simulate the NRX-A3, EP IV power run) is well underway. Option 3 of the program will be used, wherein the coolant starting enthalpy, chamber pressure, and chamber flow rate are inputs. The program will calculate the nuclear heating rate, coolant starting pressure, and chamber temperature. Preliminary evaluation of the NRX-A3, EP IV Cal Comp plot data was completed. Few instruments failed to operate during the EP IV run. However, some measurements were lost due to Channel L-08 which was inoperative, and Channel L-10 has usable traces with some "dips" and "spikes". These are being further investigated. Suspect Cal Comp data are being compared with Sanborn data.

Power spectrum analysis of the NRX-A3, EP IV data was performed at NTO in support of the DRAGON Team. Full-power hold and shut-down transient data indicate the presence of nozzle oscillations between 200 and 250 cycles per second. Excellent correlation was obtained between system pressure parameter and nozzle torus accelerometer spectrum plots at these frequencies. NRX A-2 cold flow test and theoretical calculations have confirmed that this frequency range includes the fundamental nozzle second-degree bell vibration mode. A power spectra pressure oscillation between 350 and 400 CPS was unexplained at the time of the test. Later examination of the power spectral density analysis of system pressure and nozzle accelerometers indicates that the higher frequency oscillations are generated by the mixing process in the core exit chamber. The frequencies can be correlated with the acoustic lengths in the pressure vessel-core system. An interim report of these results will be prepared. A complete volume of all power spectrum plots compiled by NTO for EP IV and EP V has been received at Sacramento. Correlation of vibrational phenomena for these two tests will be made.

Preliminary analytic results showed no flow asymmetries in the nozzle and reactor systems during the NRX-A3, EP III LH_2 run, EP IV, and EP V start transient periods. The two-phase flow condition either did not exist or existed for only a short duration. However, temperature asymmetries were observed in the torus and nozzle tube outlet plenum for approximately 25 seconds at the start of EP V power test, while the nozzle f ed was still in the gaseous phase. During this period the coolant temperatures in the nozzle torus and nozzle tube outlet plenum at reactor theta of about 300° (opposite side from the nozzle torus inlet line) were as much as 50°R higher than at other locations. Similar temperature asymmetrics were not observed in EP III and EP IV. This phenomenon is being further investigated.

An analysis is being conducted of the emergency shut-down which occurred during NRX-A3 EP IV power test. A preliminary estimate of the nozzle feed rates was made based on the flow in the feed lines. Since the determination of the nozzle feed rates is a key item in the analysis of the shut-down conditions, alternate analytic approaches will be attempted to confirm the estimated feed rate. Nozzle-tube heat transfer and tie-rod conditions are items which will be especially investigated.

Correlation of the propellant mapping results for NRX-A2 (EP V), and NRX-A3 (EP VI) is planned, with initial use of the analog computer. WANL formulae for the propellant coefficient of reactivity will be evaluated. A multi-plot data reduction program is now being developed which is expected to greatly facilitate this data analysis.

Analysis of the NRX-A3, EP VI control system dynamics tests will be made pending receipt of reproductions of the special control room Sanborn records.

C. DEVELOPMENT AND IMPROVEMENT OF DATA ANALYSIS METHODS

A four-channel (rather than a two-channel) NRX-A reflector model has been incorporated into the 364 Program. In the two-channel model, the coolant flow was divided into two parts -- the outer and inner reflectors. The four-channel model divides the total coolant flow through the reflector assembly into four -- pressure vessel outer reflector annulus, outer reflector, inner reflector, and control vane. In the new model, the coolant flow passing through the pressure vessel outer reflector annulus can be routed around the outer reflector plenum into the dome and plenum, thus better representing the actual physical configuration. In the two-channel case, the total flow is combined in the outer reflector plenum. The revised program should provide more representative temperatures in the outer reflector and dome-end plenums.

A cross-linking routine is being incorporated which will enable the reflector four-channel model to tie the pressure vessel outer reflector annulus flow into the dome-end plenum.

The entrance and exit loss coefficients in each of the reflector channels are being adjusted in the four-channel model to provide the desired flow fractions through each channel, as well as pressure drop across each channel of the reflector assembly. The flow fractions were obtained from report WANL-TME-840. Pressure drop is based on measured drop during the NRX-A2 tests.

Work progressed on the simulation of the NRX-A3, EP IV power test using the 364 computer program. Due to the extreme transients which existed in the test convergence, difficulties were encountered. However, by the end of the report the problems were sufficiently solved to permit computations to be completed as far as input was supplied (25 seconds). Evaluation of these results is underway.

A Normal Population Data Test Program No. 16155 was checked out and is ready to use for the NRX-A3 data analysis. The basic operations of the program are to test the assumption that redundant measurements come from the same normal population, and to plot the statistical mean value and confidence interval for the time mean value.

1.8.7 ENGINE SYSTEMS DATA ANALYSIS

The data analysis plan for the forthcoming NRX/EST test is dependent upon the Test Specification NJD-2 which was recently issued. The data analysis plans for CFDTS and NRX-A test series will also be included in the planning of the final data analysis plan for the NRX/EST test.

1.9 RADIATION EFFECTS PROGRAM

1.9.0 INTEGRATION & TECHNICAL MANAGEMENT

A. PROGRAM PLANNING

The test schedule for the W-2 water cooled loop at the Plum Brook Reactor Facility (PBRF) has been delayed four months because of a number of minor problems which arose following the charging maching installation in this loop. This much delay results because repairs can only be made when the reactor is shut down and the water quadrant is drained.

The schedule following for NERVA radiation effects tests is predicated upon repair of the charging machine drive motor during the next reactor shut-down, and upon maintenance of their predicted reactor schedule by PBRF:

Test Item	Test No.	PBRF Cycle No.	Estimated Date
Structural Materials	37/W402	36P	7/7 - 7/19
Accelerometers	23/W006		
LASL Structural Materials	37/LA001	37P	7/30 - 8/11
LASL Structural Materials	37/LA001/2	38P	8/15 - 8/25
Dosimetry Test	RE-3	39P	8/29 - 9/9
NERVA Non-Metals	37/W301		
Pressure Transducers	23/W508		
AGC Pressure Transducers	23/R510	40P	9/20 - 9/30
Neutron Detector	21/W003		
Strain Gage	23/W408		

An August test date is anticipated for Ground Test Reactor (GTR) Test No. 17 on bearing retainer materials, pending arrival of the test specimens at General Dynamics/Fort Worth. Delivery of all specimens is scheduled by 1 August 1965.

B. RADIATION EFFECTS TESTS PERFORMED

Radiation Effects Tests included in the GTR-16 Reactor Test completed their irradiation during this report period. The following items were included:

37/R002, tensile test specimens at LH_2 temperature;
37/R003, shear specimens at LH_2 temperature;
37/W003, WANL materials at LN_2 temperature;
37/W401, reactor mechanical components at LN_2 temperature;
37/R101, TPA bearing cage materials at LH_2 temperatures.

C. RADIATION EFFECTS REPORTS AND INFORMATION

The following REON Reports were published during this quarter:

2277, September 1964 revision, Radiation Effects Data Book (U);

2277, April 1965 revision, Radiation Effects Date Book (U);

RN-S-0199, Radiation Effects Analysis of NERVA Candidate Accelerometers;

RN-S-0210, Final Test Report for Phase One of the Countermeasure Radiation Effects Program (U);

RN-S-0217, Final Test Report for Phase I-B of the Countermeasures Radiation Effects Program (U);

RN-S-0218, Preliminary Test Report for Phase I-D (Kiwi-TNT) of the Countermeasures Radiation Effects Program (U).

1.9.1 COUNTERMEASURE RADIATION EFFECTS PROGRAM SUPPORT

Liaison continued with LASL wherein two additional Phase I-D (Kiwi-TNT) capsules were recovered at NRDS. AGU-5 was recovered on 8 April 1965 and AGY-5 on 30 June 1965. Liaison and coordination continued with the United States Army Picatinny Arsenal wherein future irradiation plans for Phase I-C were formulated. As noted under A, above, Test Reports were published on this work during April.

Fifty-two irradiation capsules for Phase I-C completed fabrication during this quarter. Twelve of these are the instrumented type to permit measurement of temperature and pressure during irradiation. Figure 35 illustrates the instrumented irradiation capsule assembly.

Eight pre-irradiation tests were performed on the instrumented capsule to determine its ultimate safety within a reactor. Figure 36 illustrates a cross-sectional view of the capsule cap to accommodate thermocouple leads, continuous path for pressure measurement, and seal-ring assembly to minimize gas leakage. Figure 37 illustrates effective sealing of the capsule after after 3.6 grams of high explosives were detonated within.

(Text continued on page 144)

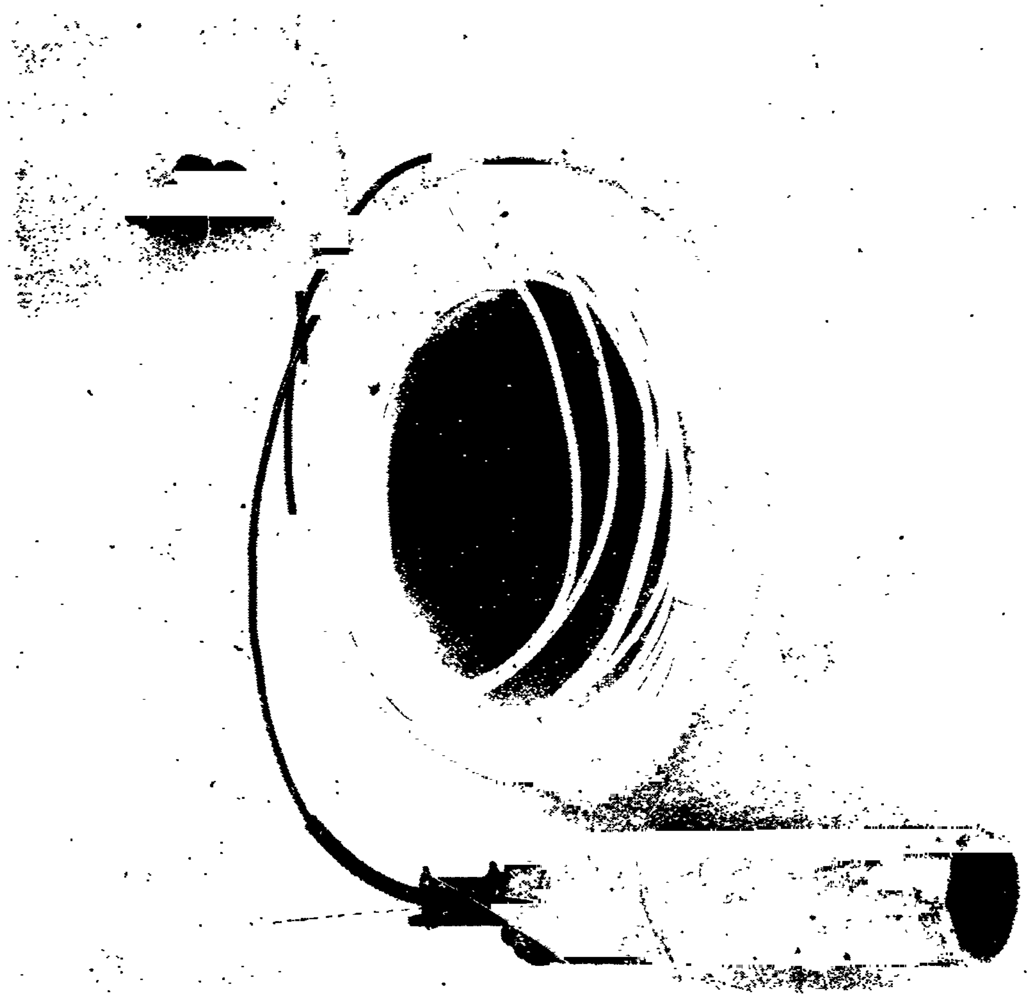


Figure 35

Instrumented Capsule Assembly

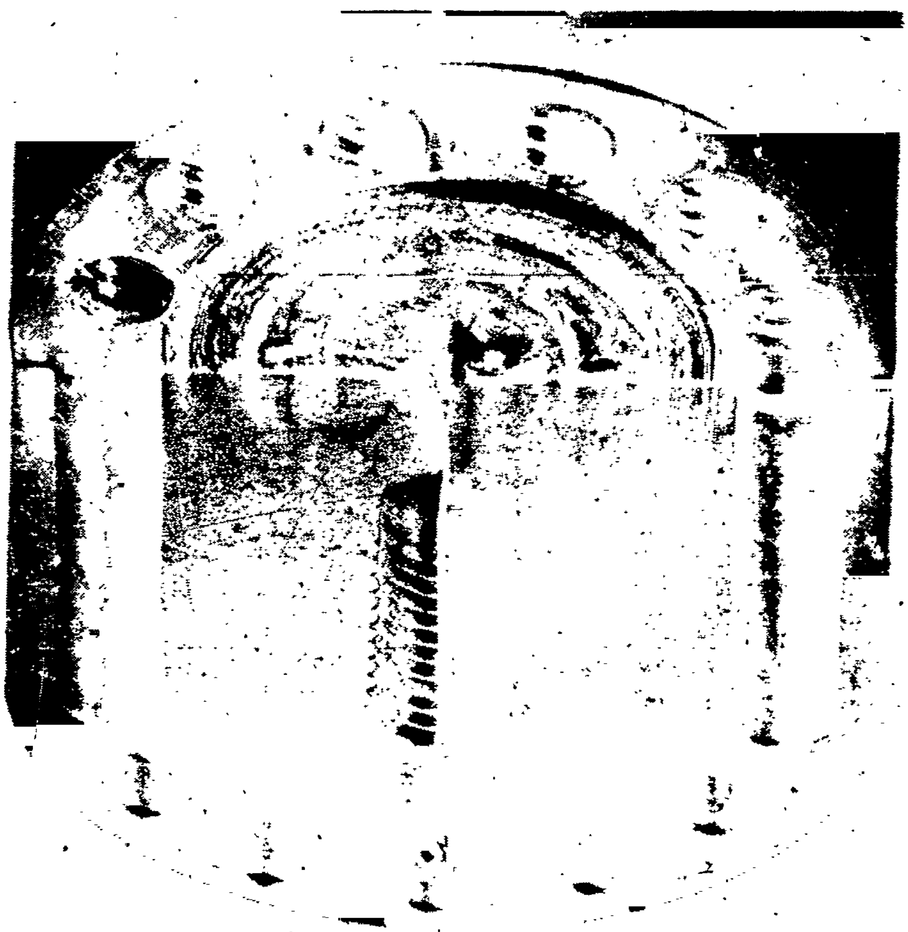


Figure 36

Instrumented Capsule
Cross Section of Cap

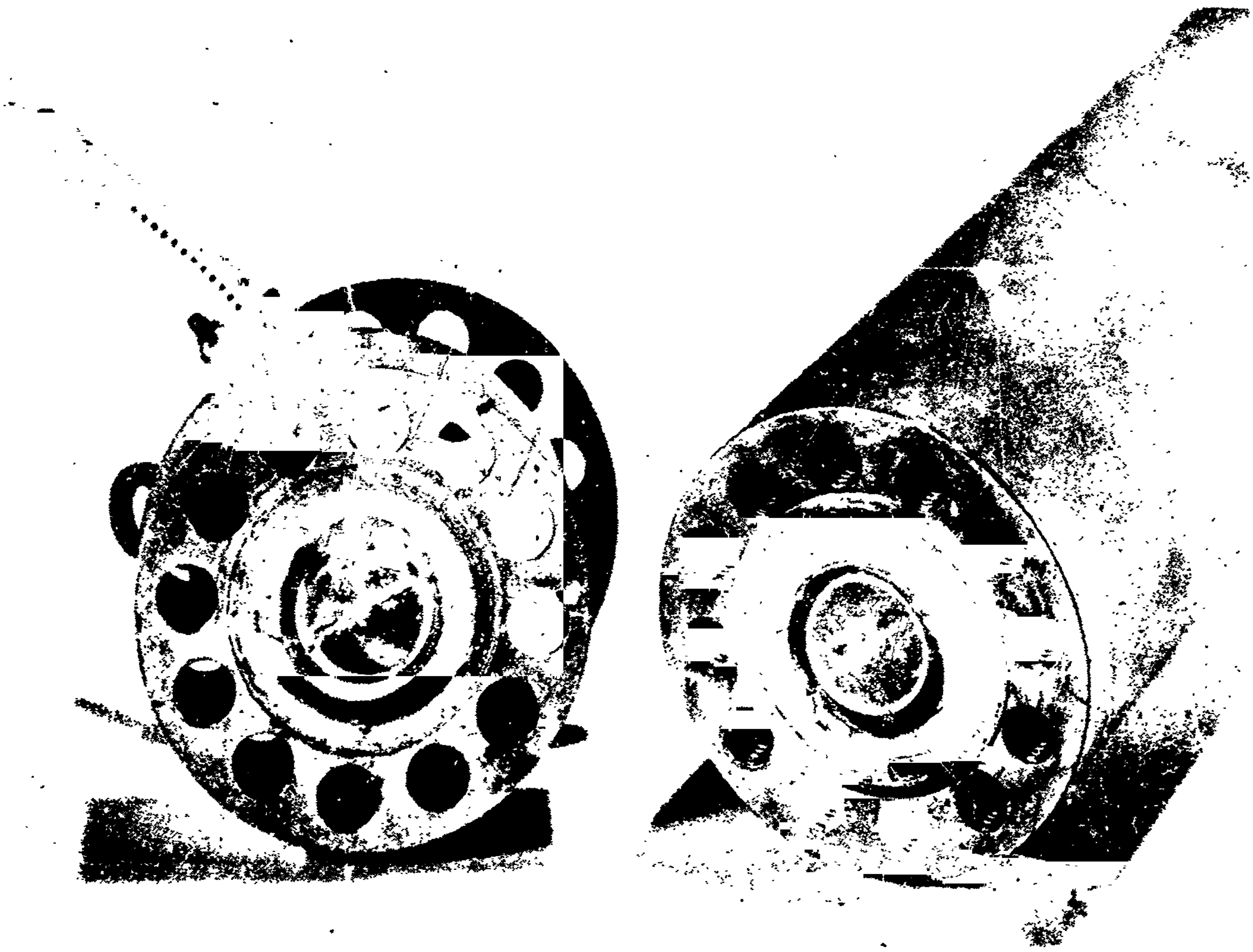


Figure 37

Instrumented Capsule
after Internal Detonation of High Explosive

1.9.2 RADIATION EFFECTS ANALYSES AND DATA BOOK

The neutron activation analysis previously performed for Irradiation Test 37/A002 was revised to account for an updated irradiation history. Neutron induced activity was predicted for an irradiation test of a mild detonating fuse (MDF) and of a propellant.

1.9.4 INSTRUMENTATION RADIATION EFFECTS PROGRAM

An Irradiation Test Capsule was designed for the second Plum Brook Reactor Facility (PBRF) instrumentation test (pressure transducers).

A method of terminating stainless steel sheathed cables was developed for use in the pressure transducer tests at PBRF.

The test capsule for Radiation Effects Test 23/R510 was fabricated. This capsule will be used in the PBRF Horizontal Through Tube-1 (HT-1).

Radiation Effects Test 23/R005 (accelerometers) was successfully conducted during the report period concurrently with the NRX-A3 reactor test. The accelerometers were tested adjacent to the reactor during reactor operation. All transducers provided output through the entire test series, and data are now being analyzed.

1.9.6 MATERIALS RADIATION EFFECTS PROGRAM

Organic tensile specimens for use in the GTR-17 irradiation test were designed. Test results from GTR-16 were evaluated, and preliminary data on property changes are presented under sub-task 2.8. The preliminary test report is in process.

The GTR-16 irradiations, as outlined under Section A, above, were completed in April. Post-irradiation tensile and shear testing, and metallographic type analyses have continued at GD/FW throughout the quarter.

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SECTION III (CONTINUED)

TECHNICAL DISCUSSION
TASK 2

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2.1 REMOTE HANDLING EQUIPMENT

2.1.0 INTEGRATION & TECHNICAL MANAGEMENT

Preliminary XE-1 engine flow diagrams are being prepared as part of the forthcoming Operational Support Plan for the XE engine.

During the report period, the interface installation drawings for the Overhead Positioning System, Floor Mounted Handling System, and the Post Operative Cell Material Transfer System were reviewed and revised. They were constantly upgraded to present the latest interfaces between the support equipment systems, the facility and facility equipment. Changes and revisions were coordinated with NRO, Vitro, and SNPO-C.

Preparation of interface control drawings for other support equipment was initiated to include interfaces between the support equipment item and test equipment, facilities and facility equipment, and other support equipment

2.1.1 OVERHEAD POSITIONING SYSTEM (OPS)

. OPS Site Verification/Acceptance Test Procedures were completed during the second quarter.

Review of the AMF, OPS Spare Parts List by AGC-REON was completed, and procurement initiated for a limited quantity of spares for installation and test support. A formal list of operational spares is scheduled for publication during the next quarter.

Operating and Maintenance instructions were completed except for the incorporation of some vendor data and possible incorporation of data gained through final testing. Publication of the final document is scheduled for the next quarter.

The basic design of the Upper Thrust Structure positioning head was completed, and drawings are scheduled for release during the next quarter. One positioning head was deleted, after an investigation revealed no requirement for the second item.

The OPS mast, trolley, inching and leveling frame, and the floating head were delivered to NRDS during this quarter.

Installation of bridge rails and OPS electrical system (Part II electrical) was completed. Basic installation of major OPS components was completed. Final installation, cleanup, checkout and acceptance testing of OPS and positioning head is scheduled for completion during the next quarter.

The terminal to terminal wiring, Phase II, was completed during the quarter.

2.1.2 FLOOR MOUNTED HANDLING SYSTEM (FMHS)

The final acceptance test specifications were published during this quarter.

The basic design of the upper thrust structure positioning head stand was completed, and drawings are scheduled for release for fabrication during the next quarter. One positioning head was deleted due to the lack of requirement for the second item.

Assembly and installation of the FMHS was completed during this quarter, and acceptance testing was initiated, with completion scheduled for the next quarter.

Design, fabrication and installation of floor load spreaders for the FMHS turntables is scheduled during the next quarter, after completion of acceptance testing on the turntables.

The terminal-to-terminal wiring was completed (Phase II) during this quarter.

2.1.3 NRX SUPPORT EQUIPMENT-REMOTE HANDLING

The Operational Support Plan (OSP) addendum for the NRX/EST was completed and reviewed by REON and published by WANL during this quarter.

Design criteria were completed and issued for the following items during the previous quarter.

Item 501, Stand, Turbopump, Remote
Item 502, Sling-TPA, NRX/EST Assembly
Item 503, Sling, Direct Radiation Shield
Item 504, Fixture, Handling, Propellant Lines, Remote
Item 505, Stand, Direct Radiation Shield

No design modifications were required to the NRX-A3 items in support of NRX/EST. Need for design modifications to equipment required for NRX-A6 cannot be evaluated at this time.

Design was completed on the following items for NRX-A3 and NRX/EST during the second quarter:

Item 273, Remote Seal Manifold Cutter (A-3)
Item 502, Remote Turbopump Lifting Fixture
Item 503, Remote Direct Shield Sling
Item 505, Direct Shield Stand

Design was completed on Item 501 Turbopump Stand during the report period.

Item 273, Remote Seal Manifold Cutter was fabricated, tested and delivered to the test site for use with NRX-A3 during the second quarter. This item was used to successfully remove the remote seal from the NRX-A3 during the report period.

The following NRX/EST items have been fabricated and delivered to NRDS for acceptance testing:

Item 503, Sling, Direct Radiation Shield
Item 505, Stand, Direct Radiation Shield

The following item has been fabricated, and is undergoing testing prior to shipment to NRDS during the next quarter.

Item 502, Sling TPA, NRX/EST Assembly

The following items are in process of fabrication, which will be completed and the items shipped to NRDS during the next quarter.

Item 501, Stand, Turbopump, Remote

Item 504, Fixture, Handling, Propellant Liner, Remote

The following WANL bid packages were reviewed and approved.

Item 1399, Acid Fume Hood Assemblies

Item 1398, Radiochemistry Sink

2.1.4 ENGINE SUPPORT EQUIPMENT - REMOTE HANDLING

The design of the Post-Operative Cell Materials Transfer System (POCMTS) was initiated at Aerojet during this quarter, data required to complete the design of this item was not available during the report period.

The design criteria of POCMTS has changed materially from the original concept. Preliminary design was completed and detail drawings were initiated during this quarter. The revised concept consists of two intercell transfer cars, seven hot cell material transfer system tables, associated electrical bus and car rails, and the necessary handling slings. The system as outlined will install the POCMTS on the West Bank (core disassembly side) of the E-MAD building post-mortem area.

Design and fabrication was initiated on the following XE-1 add-on equipment during this quarter, and all design and fabrication will be completed during the next quarter:

Item 5006, Acetylene Torch
Item 5021, High Activity Storage Car (Modified)
Item 5035, Pneumatic Shears (Hedge Type)
Item 5036, Pneumatic Shears (Hook Type)

The following add-on items were delivered during this quarter to NRDS:

Item 5014, Personnel Shield
Item 5015, T. V. System Equipment
Item 5022, Durometer-Remote

Item 5019 Periscope was delivered to NRDS for temporary installation and after use at the R-MAD building during the second quarter, has been returned to LENOX for correction of internal adjustments. It will be returned to NRDS (R-MAD) during the next quarter.

A rough draft of the preliminary XE-1 Operational Support Plan is now being revised, and will be completed and published during the next quarter.

Volume II (Provisioning List) of the XE-1 Operational Support Plan was prepared and distributed during the second quarter, and a revision is being processed for publication and distribution during the next quarter.

The design of the Interim Carriage and Spacer, for use with the Upper Thrust Structure test rig, was completed during the second quarter. The support equipment required for the UTS interface test rig was fabricated and delivered to the UTS test rig site at Sacramento during this quarter.

2.1.6 ENGINE INSTALLATION VEHICLE (EIV), MANNED CONTROL CAR (MCC), AND LOCOMOTIVE

A preliminary integrated evaluation program establishing the interworking environment and agreements between the engine component interface development activity and the MCC/EIV completion and evaluation activity at the Sacramento checkout area was completed. Initial viewing study parameters and planning were prepared and a preliminary MCC/EIV Operators Manual was completed. Updating of the MCC and EIV equipment specification was initiated.

The basic design of the EIV lateral and azimuth carriage grippers was completed, and approximately 30% of the detail drawings have been completed, and approximately 30% of the detail drawings have been completed during this quarter. Com·'ications due to the overall EIV/MCC system changes and additions account for the low percentage of completion of the detail drawings.

The design of corrections and modifications required for the MCC and EIV were initiated during the second quarter and have been continued during this quarter. Emphasis was placed on the clearing of open receiving items, the umbilical actuator operation, improving the closed circuit T.V. system, improving the MCC parking brake, and reviewing the MCC controls scheme.

The Phase II (terminal to terminal) wiring required for EIV operation in the E-MAD initiated during the second quarter has been completed during the report period.

2.2 GROUND SUPPORT EQUIPMENT - CHECKOUT & TEST

2.2.5 ENGINE EQUIPMENT - CHECKOUT AND TEST

Preparation of Design Criteria for the XE-1 and XECF items is dependent upon identification of these items in the Operational Support Plan. When the OSP is completed, preparation of Design Criteria will be continued.

Preliminary operational flow diagrams for XE-1 were initiated during the second quarter.

Volume II, Provisioning List, of the XE-1 OSP was distributed, and a revision to this list has been initiated, and will be distributed during the next quarter.

2.2.8 ETS-1 TEST STAND CONTROL SYSTEM

TSCS system concept design drawings were released 28 May and approved by SNPO-C on 11 June. A design requirements freeze was initiated 1 July.

Preliminary inputs were being incorporated into TSCS design.

The WANL mockup equipment was completed and installed into the TSCS mockup and the TSCS racks were delivered to Sacramento during this period.

The TSCS mockup and XE Engine breadboard controller circuits were integrated and operating characteristics of the system were verified to be within design limits.

Tests of the TSCS mockup using the preliminary XE Engine computer model were initiated.

2.3.3 NRX SUPPORT EQUIPMENT - LOGISTICS, TRANSPORT, AND MAINTENANCE

The Operational Support Plan addendum for NRX/EST and Volume II (Provisioning Data List) of the NRX/EST OSP were published.

No new requirements for AGC supplied support equipment were defined during the report period.

Final consent on WANL purchase orders for the Item 1706 Reactor-In-Vessel Shipping Container was given during the report period, and WANL bid packages were reviewed and approved for Accelerometers (for use with Item 1706); and for Oscillograph and amplifiers (part of Item 1224 - Shipping Instrumentation Recorders and Cabinets).

2.3.5 ENGINE SUPPORT EQUIPMENT LOGISTICS, TRANSPORT, AND MAINTENANCE

Preparation of the Design Criteria for the XE-1 items is dependent upon identification of these items in the Operational Support Plan. When the OSP is completed, preparation of Design Criteria will be continued. However, a preliminary Operational Support Plan for XE-1 was initiated during the second quarter, is now being revised, and will be published during the next quarter.

Volume II, Provisioning Data List, of the XE-1 OSP was distributed during the quarter, and a revision is being processed and will be published during the next quarter.

All design activity for the CFDTS support equipment was completed, and the equipment used to assemble and move the unit to the Sacramento Test Area, where it was installed in the test stand. A test of the CFDTS was performed during the report period. All items of support equipment for CFDTS were completed, delivered to the Assembly area and used in the assembly, transport to the test area, or installation of the CFDTS in the test stand during the report period. Support equipment for the CFDTS will be evaluated, in detail after the CFDTS firing and return to the assembly area.

2.4 INSTRUMENTATION

2.4.0 INSTRUMENTATION SYSTEMS

The entire NERVA instrumentation development, procurement, and testing efforts were monitored and directed by conducting various technical meetings and close technical cooperation between REON, LRO, WANL, LASL, and NTO.

The April edition of the NERVA Instrumentation Data Book was published as Volume III, Book 3, which consisted of final NRX-A3 data.

Instrumentation Procurement Status Reports covering CFDTS (completed in May) and NRX-EST were submitted to SNPO-C for April, May, and June.

2.4.2 NRX INSTRUMENTATION

The Measurement Requirements List (MRL) for NRX/EST has been revised and upgraded as required based upon input through 18 June 1965. The Planning Parts List for NRX/EST was completed and has been revised as changes have been received. The MRL for NRX-A5 dated 15 June 1965 is being reviewed.

The instrumentation kit installation drawings for NRX/EST have been completed and released with two exceptions, which are expected to be released early in July.

Four modification kits were prepared to incorporate the changes to the NRX/EST MRL. The requirements have been defined and the drawings will be started early in July.

All requisitions have been issued for the NRX/EST instrumentation kit and for all "long-lead time" equipment known to be needed for the mod kits.

At the end of the reporting period 54% of the NRX-EST instrumentation kit had been shipped to NRDS.

An NRX-A2 post-operative evaluation report RN-S-0215, Final Report, NRX-A2 Nozzle Chamber Tungsten-Rhenium Thermocouples, was published in May.

Analysis of instrumentation data for NRX-A3 was partly completed. Of the 183 channels that were instrumented for NRX-A3 only 9 (or less than 5%) are questionable. The hydrogen leak detection system for NRX-A3 functioned normally throughout the tests. A final report, RN-S-0238 Instrumentation Evaluation, NRX-A3 Tests, will be published during the next report period.

2.4.3 XE-ENGINE INSTRUMENTATION

A Measurement Requirements List format has been agreed upon and the first edition is being compiled. The cooling analysis studies for the remote assembly concept are being redirected and will be expanded to a transducer analysis when the XE-1 Measurement Requirements List is released.

2.4.6 NON-NUCLEAR INSTRUMENTATION DEVELOPMENT & QUALIFICATION

A. MANAGEMENT

The NERVA Instrumentation Design Review Meeting was held at WANL in Pittsburgh on 9-10 June 1965. A formal report will not be published for this meeting, but minutes were written and a limited distribution made to the attendees.

Reports are being prepared on the evaluation of test results for pressure transducers and accelerometers tested in GTR-14, and for the Statham vacuum deposited strain gage pressure transducer elements tested in GTR-15.

B. NRX-A3 INSTRUMENTATION STATUS

1. Temperature Transducers

a. Copper- onstantan Thermocouple

Figures 39 and 40, respectively, show immersion and surface mounted thermocouples mounted on the NRX-A3 engine. Out of 67 copper-constantan data channels, 2 immersion sensor channels showed an abnormal loop resistance increase (greater than + 14%), one surface sensor channel an abnormal loop resistance decrease (greater than - 49%), and one surface sensor channel showed an open shield. It is not known whether these discrepancies were induced by the sensors or by related channel cabling.

During EP-IV, EP-V, and EP-VI all channels indicated a negative millivolt drift because of a temperature variation induced by a nuclear field in the test-car-mounted Pace thermocouple reference junction. During EP-V the drift rate (-0.00066 mv/sec) was sufficient to produce a -0.12°R/sec variation in recorded inlet temperatures in the propellant feed line, nozzle torus, and reflector plenum during the full-power run. Several data channels were not recorded during EP-VI because the negative drift rate exceeded normal Cal-Comp ranging. Attempts are being made to recover this off-scale data. Although manual data reduction techniques have been used to compensate for the drifting thermocouple reference, such techniques can reduce gross errors but add to the overall measurement uncertainty. Obviously a new radiation-hardened thermocouple reference system will be required to support future testing.

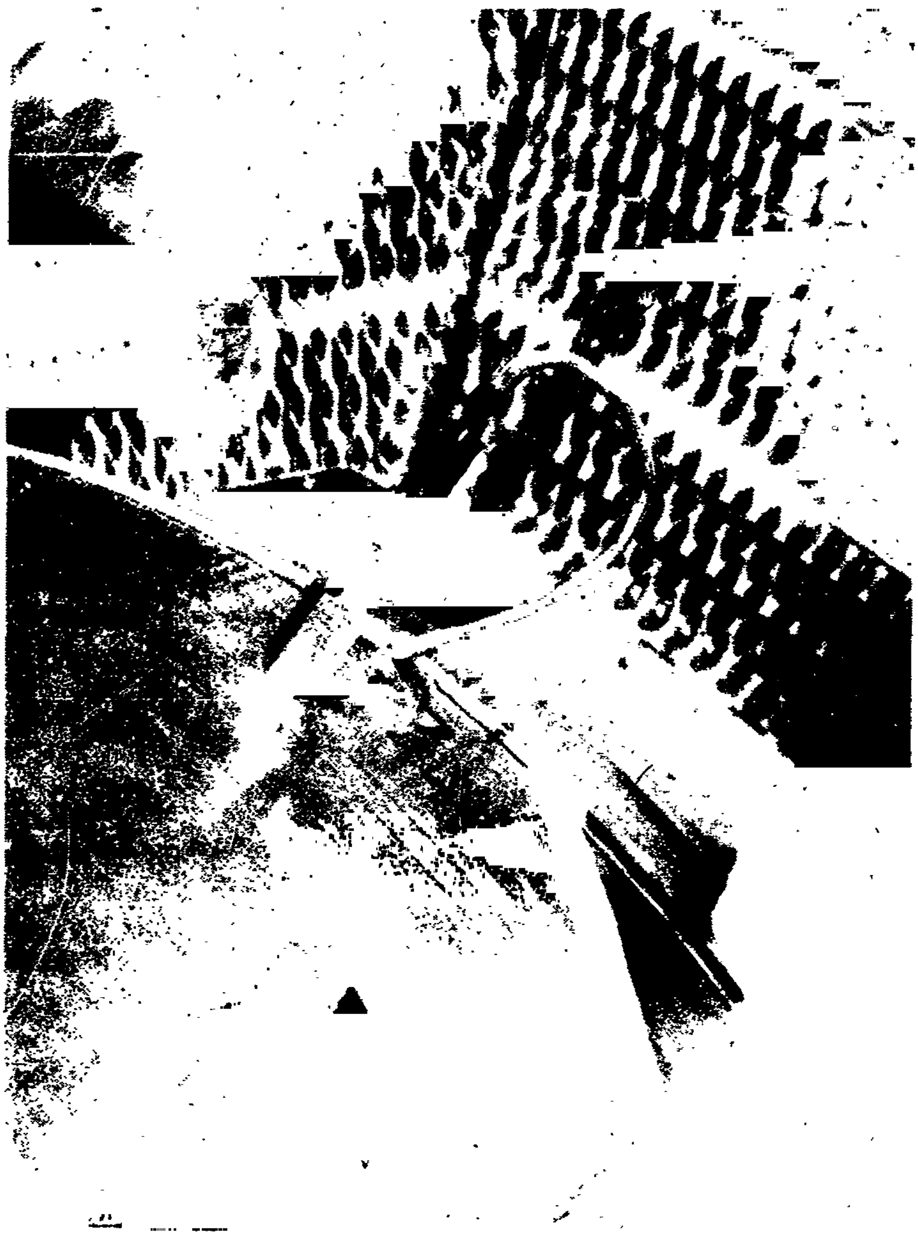

Figure 39

Copper-Constantan Thermocouple

Mounted in Nozzle Outlet

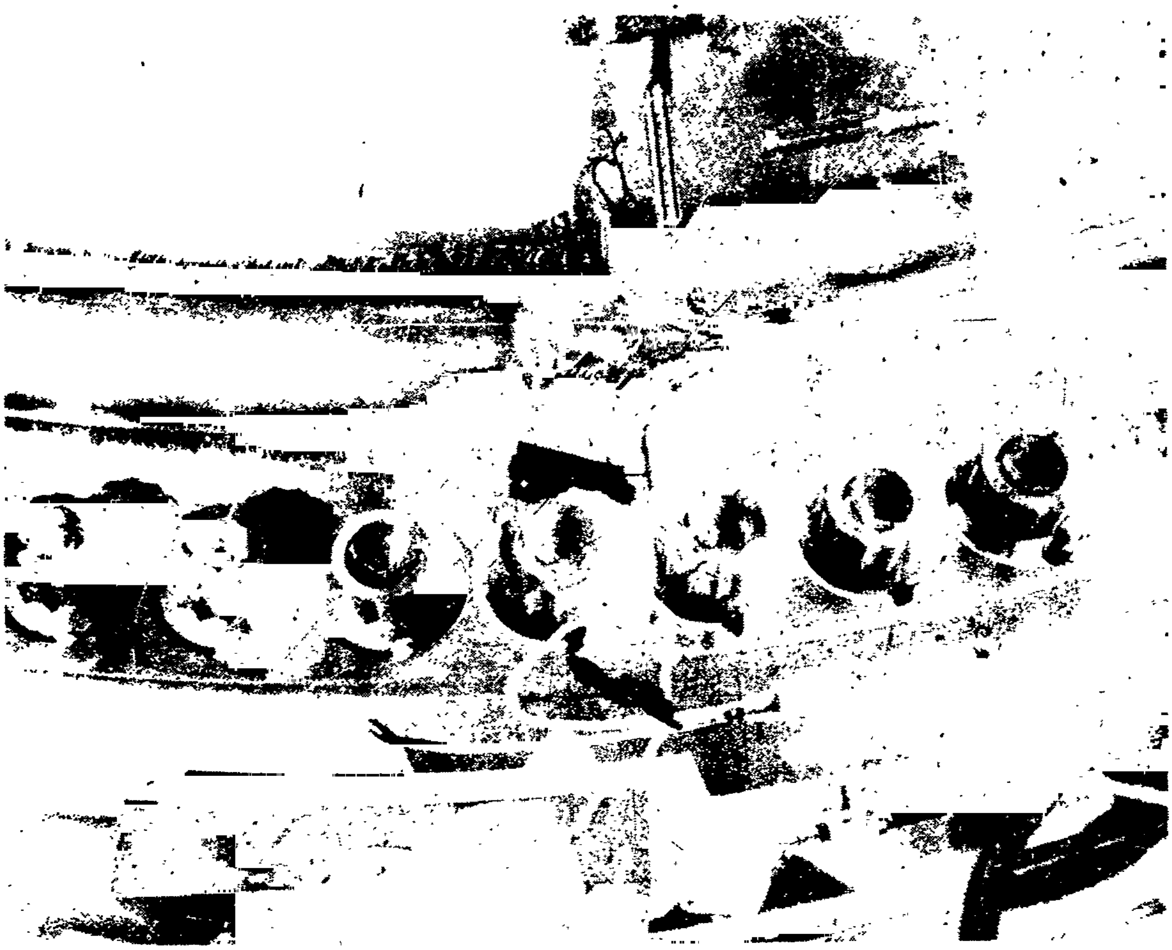

Figure 40

Copper-Constantan Thermocouple
Surface Mounted

Thermocouple channel system noise was excessive for measurements below 145°R because of the low thermoelectric sensitivity of copper-constantan in the cryogenic region. Although the noise level was small, electrically (± 0.7 mv), it was sufficient to produce a ± 20°R variation in recorded cryogenic temperature data. It should be noted that relatively noise-free platinum resistance temperature sensors were located in all cryogenic regions monitored with Aerojet thermocouples so that no cryogenic data was lost because of thermocouple channel noise.

The only visual damage incurred by copper-constantan thermocouples was a deterioration of the Epon-Versamid potting material used in the thermocouple extension cable splice housing. The deterioration did not produce any known temperature data degradation.

The present overall measurement accuracy requirement for copper-constantan thermocouples is ± 15°R within the 35 to 655°R range, while the thermocouples in use have an accuracy of better than ± 8°R within this range. However, because of their low sensitivity (3 microvolts/degree) in the liquid hydrogen region, the approximate 0.7 millivolt system noise, and the ± 1.2% system accuracy, it is not possible to obtain data with less than 50°R uncertainty in these temperature regions. Above 300°R, measurements satisfy the overall accuracy requirement. Since the thermocouples have been developed to the maximum extent, future temperature measurements in the liquid hydrogen regions will rely on platinum resistance transducers. No further development is planned for thermocouples.

b. Platinum Resistance Temperature Transducers (RTT's)

All RTT's provided failure-free service during this test series. Temperature data acquired during steady-state power-run levels showed a small positive increase, the magnitude of which approximated that predicted from the expected fast-neutron-induced transmutation effects within platinum. No visual damage was incurred by the platinum resistance temperature transducers.

Temperatures must be known to within 1°R for engine system pump tests where the NPSP must be determined. In a non-nuclear environment the present RTT design is accurate to within 0.1°R at liquid hydrogen. However, the data system contributes a ± 8°R uncertainty to temperature measurements in liquid hydrogen regions, and expected neutron degradation can contribute up to 3°R additional bias error. At this time, even under the test car shield on EST or behind the engine shield on XE, the neutron environment is high enough to make the transducer performance marginal even if no system error were present. The additional 1.2% data system error in Test Cell "A" makes the meeting of accuracy requirements unattainable.

Further RTT development is required to reduce neutron degradation or its effect to satisfy the 1°R accuracy requirement for NPSP measurements. The exact mechanism of nuclear radiation damage in platinum should be determined and various plans for its circumvention should be investigated.

c. General

Both the thermocouple and RTT transducers experienced an increase in their respective loop resistances during the NRX-A3 test series. The resistance increase, expressed as a percent of the pre-test channel loop resistance, is shown below:

Average copper-constantan immersion thermocouple channel loop resistance increase	+ 0.22%
Average copper-constantan surface thermocouple channel loop resistance increase	+ 0.34%
Average platinum resistance temperature transducer channel loop resistance increase	+ 8.07%

The exact cause of this resistance increase cannot be determined, since the resistance measurements were made with a 2% instrument under different environmental temperatures. Post-test laboratory calibrations should demonstrate whether the resistance change may be attributed to nuclear radiation effects.

d. Thrust Chamber Temperature Transducers

The four tungsten-rhenium thrust chamber thermocouples used on NRX-A3 functioned throughout the full-power tests and indicated temperatures within 100°R of each other. The maximum average temperature during the full-power hold on EP-V was 3840 ± 100°R. During the two low-power tests (I and IIIA) one thermocouple (T-141) intermittently open-circuited, probably because of a faulty connector somewhere in the circuit.

Figure 41 is a photograph of the NRX-A3 engine during disassembly. The arrow indicates a thrust chamber thermocouple and the large loop in the extension lead required to meet minimum bend radius considerations. The thermocouples now being built for NRX-EST have a right angle extension which eliminates this vulnerable loop.

The problem of reference temperature variation is also under development in connection with NRX-A3. The thrust chamber thermocouples used a Lab-Line reference temperature bath refrigerated at 492°R (ice Point). This bath, in turn, was monitored by a copper-constantan thermocouple which used a Pace reference junction. Both varied during the full-power runs. The Lab-Line apparently drifted upward because of excessive test car air temperature; the Pace drifted because of air temperature and radiation effects. This problem is being corrected by raising the reference temperature to 512°R, using heavier duty refrigeration equipment, and by using a resistance temperature transducer rather than a thermocouple to monitor the Lab-Line temperature. The RTT makes absolute temperature measurements, whereas the thermocouple makes relative measurements that must later be compared to an absolute measurement. The Pace, although eliminated from measurements with the Lab-Line, is being made less sensitive to radiation and modified so that ten spare channels can be used with tungsten-rhenium thermocouples if necessary.

The high-temperature carbon-resistance furnace was reworked at the Aerojet test facility to improve the thermal insulation and to better match the heater element to the power supply. These improvements have raised the upper temperature limit from 4700°R to 5000°R.

Figure 41

Tungsten-Rhenium Thermocouple
on NRX-A3 Engine

REON Report RN-S-0125, NRX-A2 Nozzle Chamber Tungsten-Rhenium Thermocouples, was issued in May 1965. This is the final report on the performance of the tungsten-rhenium thermocouples on NRX-A2.

2. Pressure Transducers

a. Discussion

Four engine-mounted linear variable differential transformer (LVDT) transducers were used on the NRX-A3 engine to monitor engine pressure. Transducer P-100 was located on the propellant feed line, P-130 on the nozzle torus, P-150 on the nozzle chamber, and P-200 on the nozzle tube outlet. An LVDT pressure transducer is shown in Figure 42 as it is mounted on the engine nozzle chamber. Test-car-mounted pressure transducers were used as a backup for these measurements.

The data from the NRX-A3 test series have not yet been fully analyzed. The NRX-A3 EP-IV data show that the wide-band data deviates considerably from the narrow-band test-car backup data. The narrow-band data of EP-IV and EP-V tests agree with REON's analytic predictions, and show a high correlation with respect to each other. The wide-band data for the LVDT transducers and test-car-mounted transducers show problem areas. These problems will be resolved as the data are analyzed.

The present mounting arrangement of the engine-mounted transducers is illustrated in Figure 43, which shows the associated mounting bracketry, impulse lines, and coolant lines with manifolds. Figure 44 illustrates the flush-mounted installation approach which simplifies installation problems by the elimination of mounting bracketry, coolant lines, impulse lines, and coolant manifolds. The frequency response of the system is also improved by the elimination of the impulse lines.

The flush-mounted transducer uses a standard AND 10050 modified internal thread boss and associated K-seal for its mounting arrangement. This boss is used as the heat sink for conducting the heat generated in the transducer by gamma heating to the nozzle jacket. The flush-mounted transducers will be used in gamma heating environments as high as 1.25 watts/gram.

(Text continued on page 175)

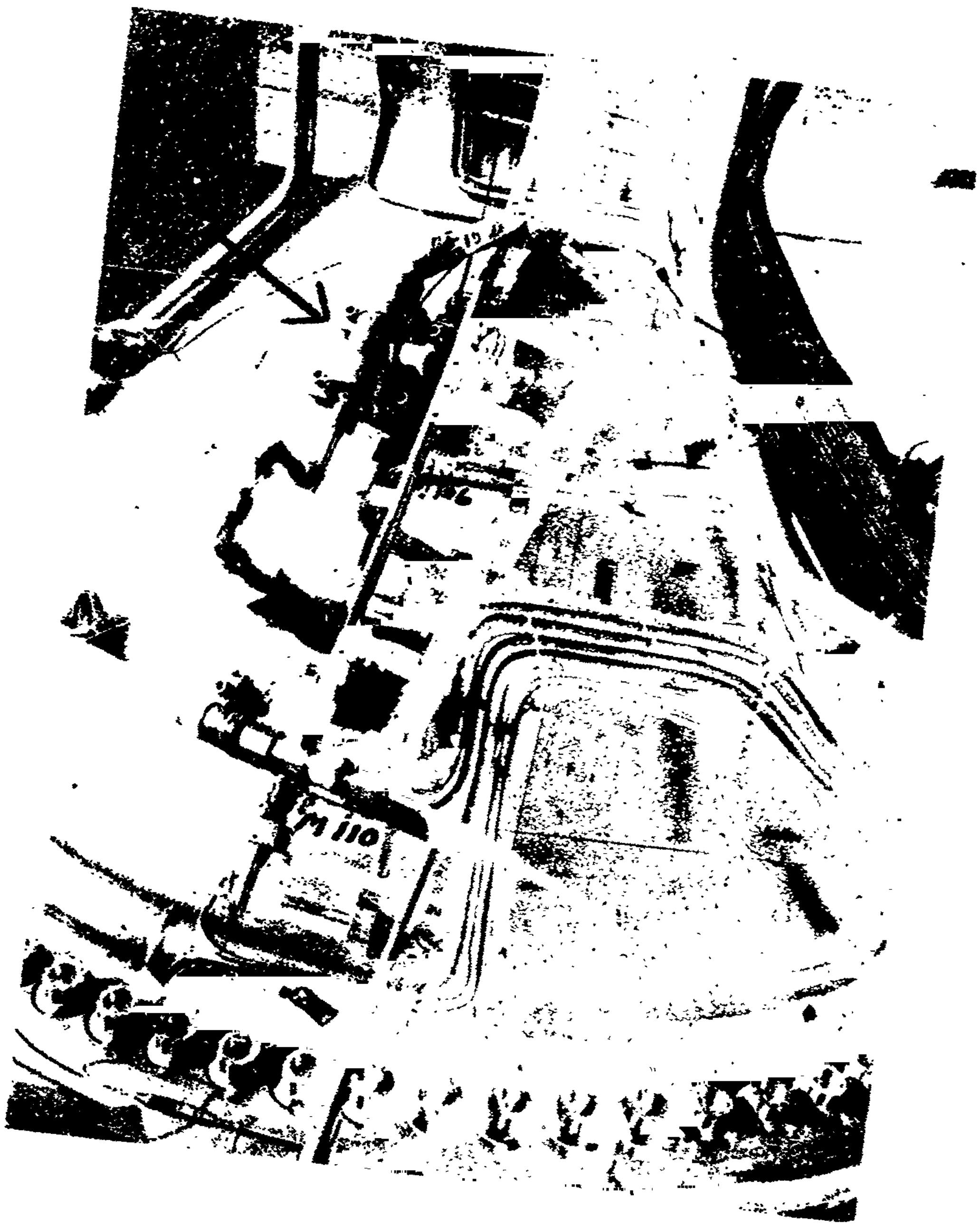

Figure 42

LVDT Pressure Transducer
Mounted on NRX-A3 Nozzle Chamber

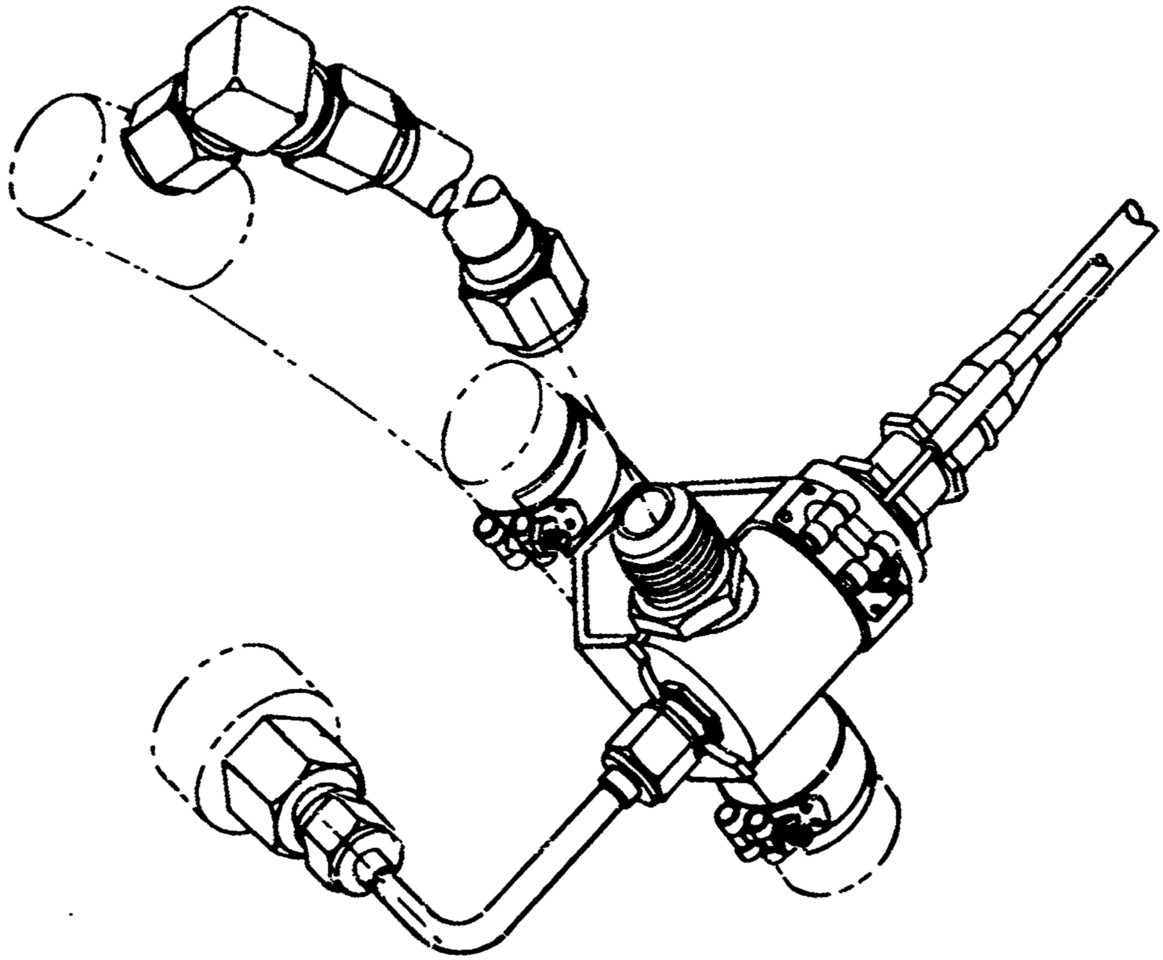

Figure 43

Present Mounting Arrangement
Engine Mounted LVDT Pressure Transducers

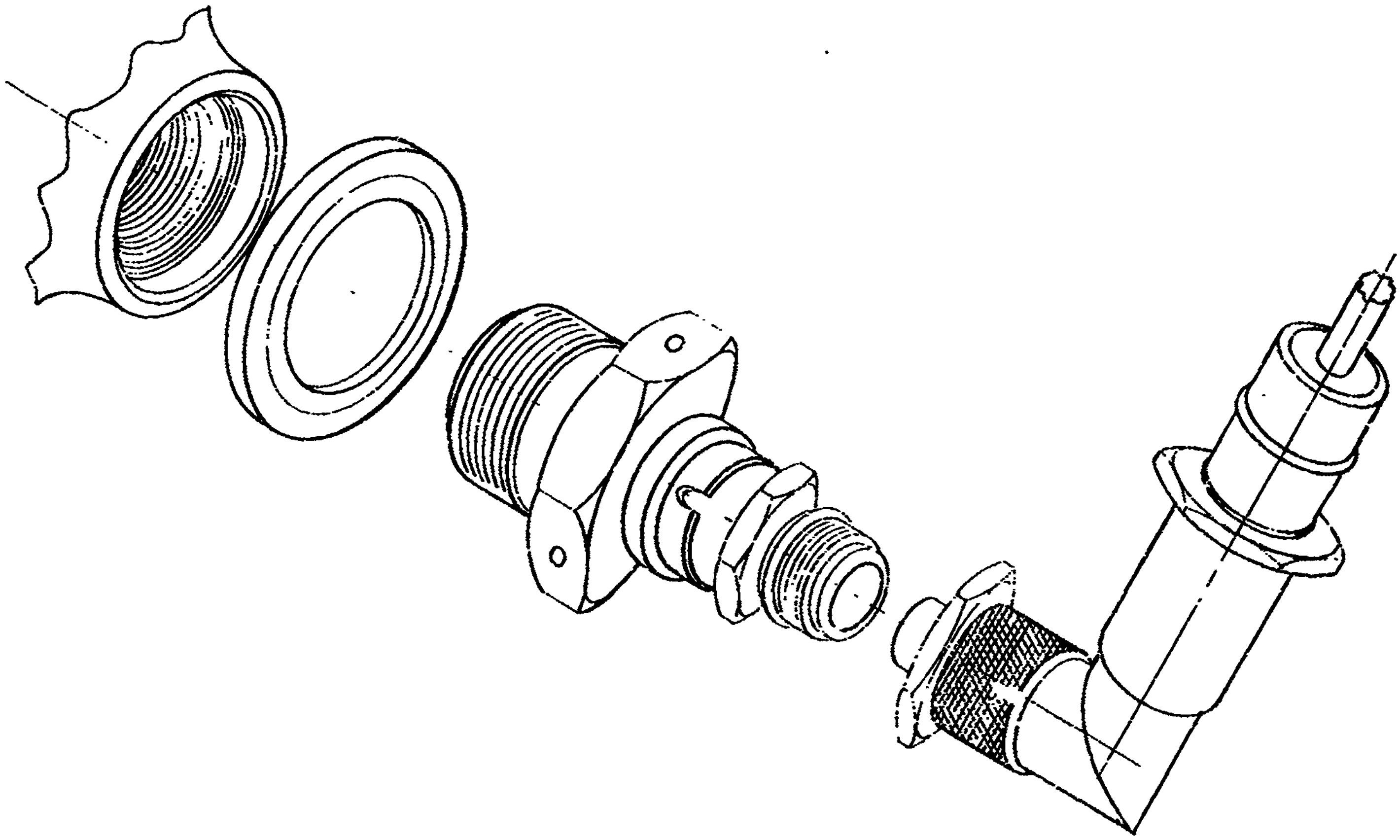

Figure 44

Flush-Mounted Installation Approach
Engine-Mounted LVDT Pressure Transducers

b. Candidate Transducers

There are three candidate transducers for the control and diagnostic pressure transducer development program. Requirements for control pressure transducers are + 1% full-scale accuracy and within $\pm$ 3 db at 16 cps for frequency response, while requirements for diagnostic pressure transducer requirements are $\pm$ 10% full-scale accuracy and response to 700 cps. Because of the nature of the control pressure transducer requirements and the proposed designs of the three candidate transducers, these designs will probably be able to meet the diagnostic requirements. Therefore the three candidates may be referred to as control or diagnostic transducers.

(1) Consolidated Controls Corporation LVDT Type

The first candidate is an LVDT transducer type similar to the LVDT internal design of the NRX-A2 and NRX-A3 LVDT, with the exceptions that the air gap between the outside coil and inner LVDT housing is filled with a mica-powder base filler and a diaphragm is used instead of a bellows. The natural frequency of this transducer is 3000 cps, as compared to 1500 cps of the present LVDT design. A thermal profile of this candidate is shown in Figure 45 when operating in a gamma environment of 1.25 watts/gram. The values are shown in degrees Rankine with the heat sink boss interface with the nozzle jacket at 116°R. The 1.25 watts/gram is higher than for the NERVA nozzle conditions, but even at this level the thermal profile indicates that this candidate will operate successfully in the environment.

(2) Standard Controls

The second candidate uses the standard tube type force summing member. This system employs the bonded strain gage configuration of a balanced Wheatstone bridge with two active legs. Karma wire, which has a low temperature coefficient of resistivity of $\pm$ 0.00001 ohms/°R in the 400 to 700°R range, is used as the strain wire. The bonding agent is Pyre M.L. Varnish which has shown excellent radiation resistant exposure to 3 x 10^9 rads of either 1.17 and 1.33 Mev gamma radiation or 2 Mev electrons. This dose produced essentially no change in the properties of the material. A thermal profile of this candidate

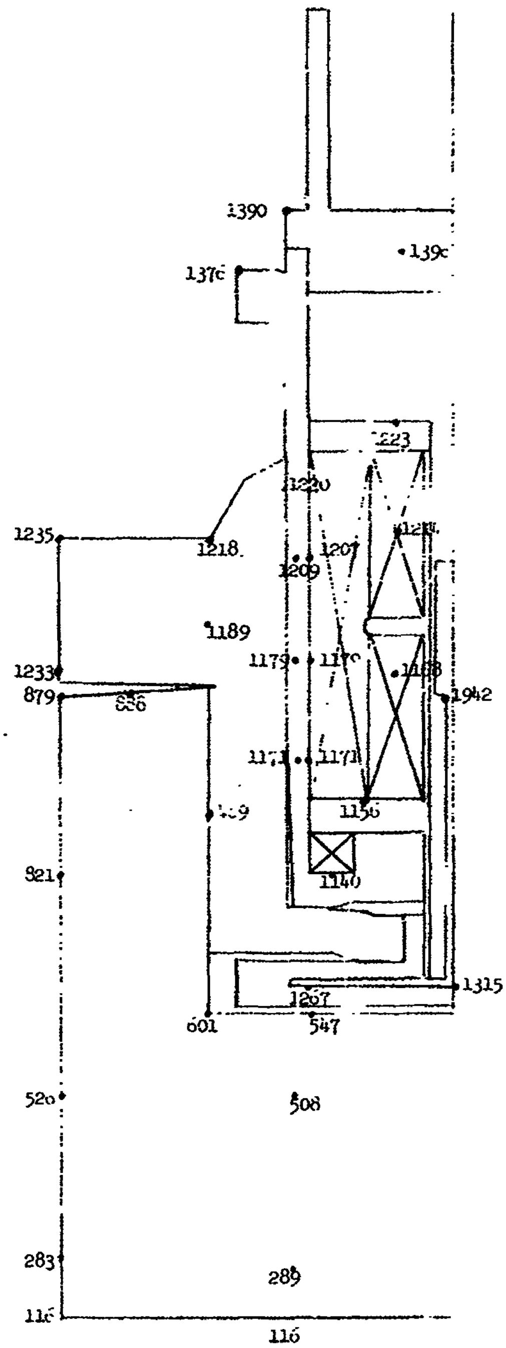

Figure 45

CCC Mod 412M Pressure Transducer

Thermal Profile - ^{o}R

Gamma Environment - 1.25 watts/gram

transducer is shown in Figure 46 when operating in a gamma environment of 1.25 watts/gram. The values are in degrees Rankine. The results indicated are very favorable for operation in this type of environment. The interface between the boss and nozzle jacket is 120°R for the values shown in the figure.

(3) Statham Instruments

The third candidate is a bonded-film strain-gage vacuum deposited on a transducer diaphragm. It employs stress-null-zone-oriented bridge patterns. The resistance of the bridge legs changes as a function of pressure induced strain. When an edge clamped flexible diaphragm is subjected to a differential force, the diaphragm is stressed in tension in the center of the diaphragm and compression stressed near the diaphragm edge. The bridge pattern design is optimized to utilize both the radial and tangential types of stress.

To obtain optimum bridge sensitivity, obtain stability, and minimize heating effects, the same composition and uniform thickness are maintained throughout all portions of the bridge legs. Each leg has a large area to aid in heat dissipation. Four active legs are used; two opposing legs at the center of the diaphragm and two opposing legs near the edge of the diaphragm. The diaphragm is Type 410 stainless steel, the strain gage is made of chromium-silicon, and the insulation is silicon monoxide. No organic materials are used, which makes this type of transducer ideal for use in a radiation environment. A thermal analysis of the pressure transducer (based on a gamma field of 1.25 watts/gram) resulted in the temperature profile illustrated in Figure 47. The results indicated are very encouraging for the transducer operating in this severe gamma field. The boss and nozzle interface surface was at 110°R for the values indicated.

Non-nuclear tests are being conducted on the three candidates at the REON Controls Laboratory.

The Plum Brook tests scheduled for May 1965 have been rescheduled for late July to replace the early CCC cooled LVDT design with the boss-mounted LVDT design. Another PBRF test is scheduled for September to evaluate the other two designs. Evaluation units of the Standard Controls strain gage design will be mounted on the NRX/EST nozzle to obtain performance data.

(Text continued on page 180)

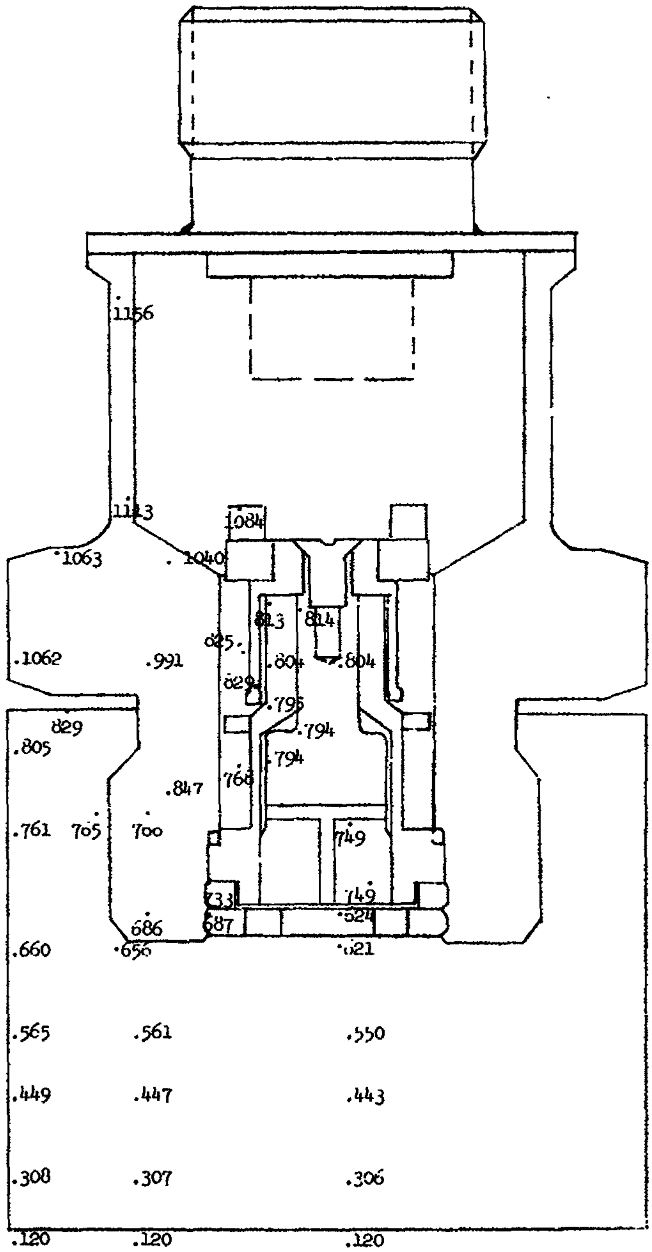

Figure 46

Standard Controls Mod. 170-9 Pressure Transducer

Thermal Profile - ^{o}R

Gamma Environment - 1.25 watts/gram

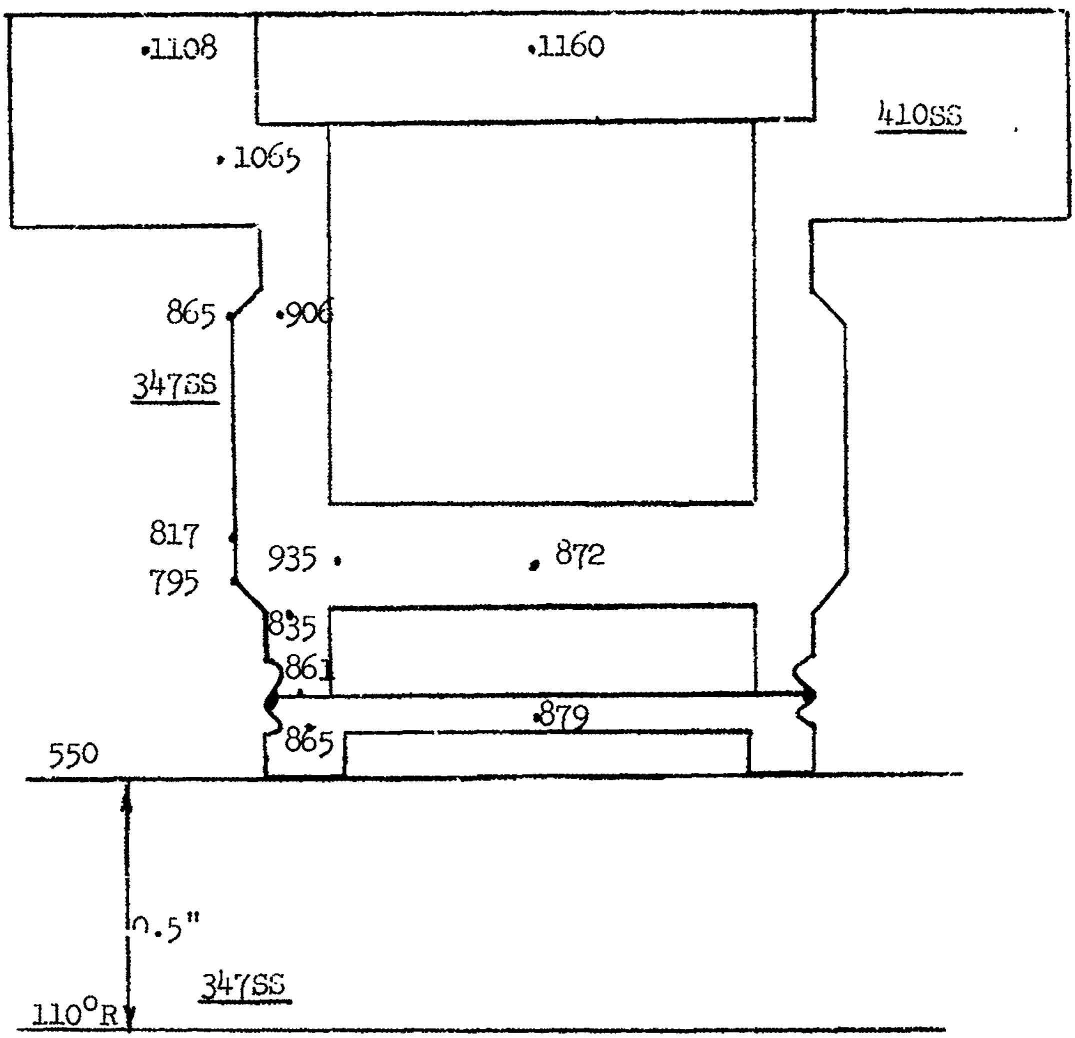

Figure 47

Statham Mod. P802b Pressure Transducer

Thermal Profile - °R

Gamma Environment - 1.25 watts/gram

3. Strain Gages

The strain gages used on the NRX-A3 engine consisted of two sensing elements and two dummy elements connected to a full Wheatstone bridge circuit. The sensing mechanism consisted of two parallel tubes attached to a common weld flange by a single line weld along each tube (Figure 48). The sensing element and its associated dummy element were contained in each tube and insulated with tightly-packed magnesium oxide. The four wires from each tube passed through a transition piece into a termination box where the bridge circuitry was completed. External pins were provided on the junction box for electrical connection. P/N 706720-1 (IDB SS-18) was used on the NRX-A3 pressure vessel and forward dome; P/N 706721-1 (IDB SS-19) was used on the steel nozzle.

During the complete series of NRX-A3 tests, 6 out of 46 gages experienced some major difficulty. Approximately half of these failures were on channels using sheathed cables, although only 14 channels used this type of cable. The cause of the failures on all six channels has not been fully determined, and it should not be assumed that the sheathed cables contributed to the higher failure rate. It is known that one bridge became grounded on the test car, that another circuit increased in resistance during the run, and that some bridges became permanently off-set during the run, while other malfunctions are not yet explained. After the test series it was discovered that some of the spare sheathed cables had been improperly manufactured and did not have ground continuity across the sheathed-cable/flex-cable transition. This could have accounted for excessive noise on some of the channels. An inspection of the used cables will be made at NRDS when the radiation levels permit.

Post-test inspection of the gages revealed that welding and cable tie-down techniques are adequate for the NRX series engines, for there was no indication of any gage or tie-down loosening as a result of the tests.

The strain gages selected for use on the NRX/EST engine are the same as those used for NRX-A3 except that an integral lead has been provided, the element is shorter, and the bridge resistance is less Part Number 1114852-19 (IDB SS-21) has been selected for use on the NRX/EST nozzle, and part numbers 1114852-59 and -69 (IDB SS-22) for use on the dome and pressure vessel.

Figure 48

Strain Gages
Mounted on NRX-A3 Nozzle

4. Cables and Connectors

Since future engine configurations will require the use of metal sheathed cables, a concentrated effort is being expended to fulfill this requirement. Feasibility tests are being conducted using various sheath and connector combinations. To date it has been demonstrated that, with the present techniques and materials, NRX engine cable configurations can be supplied. However, future engine environments are expected to be far in excess of that experienced on NRX, and therefore a completely new design approach is being considered. For example, on the XE engine there will be little convective cooling as was experienced on NRX. As a result, temperatures approaching the melting point of copper will be experienced in close proximity to the pressure vessel. Careful consideration is being given to the use of stable, high temperature alloys, cable routing, and cooling methods to solve this problem.

Other efforts during this quarter have consisted of a preliminary vendor capability study with the investigation of various metal sheathed cable to connector transition concepts being evaluated and tested. Tests to date have consisted of evaluating the effectiveness of the connector interface seals, and various leak, temperature, insulation, and welding tests. These tests are all preliminary and are not conclusive, but all show satisfactory promise for the future.

Other studies inc [illegible]de the effects on the individual transducers by the use of allo[illegible] [illegible]uctors in metal sheathed cables. These studies are related to magnetic coupling and common mode injection. Much more effort is necessary to determine the effects of extreme temperature variations on the cables and the subsequent effect on the transducers.

2.4.7 NES - DUCT INSTRUMENTATION

A. PERMANENT INSTRUMENTATION

Engineering surveys of Aero Research Instruments and Temptron Division of Consolidated Controls Corporation were completed, and a report was published which reflected the capability of each company to manufacture the metallic sheathed cabling that is integral to each instrumentation component. The wide cable cost differentials between these two companies resulted in the selection of Aero Research as the cable supplier for all component manufacturers, except that Temptron is the supplier for limit switches.

Cable specification REON-90052 was changed to incorporate a more stringent acceleration testing method for the NES duct metallic cables.

Initial bids were received from all prospective suppliers of the instrumentation components. Suppliers Information Requests (SIR's) and drawing changes were prepared and issued to reflect vendor exceptions to technical and quality control requirements. Change requisitions were issued to incorporate these changes.

The instrumentation boom design was changed to accommodate additional accelerometer cables as a result of the addition of measurement requirements on the forward and aft duct trunnions. A picture of the instrumentation boom is shown in Figure 40. Procurement of this item was completed in late June.

The permanent instrumentation installation drawing was started and is approximately 50% complete. This drawing will show installation details for all permanent and temporary duct mounted components, the instrumentation boom, the gaseous nitrogen system for the upper clamp activation air motors, and the buffer zone purge and the steam bellows purge systems. The routing and tie-down details for approximately 100,000 feet of metallic cabling and 200 feet of tubing will also be reflected on this drawing. Requisitions were issued to procure these parts.

Figure 49

Instrumentation Boom

Component mounting hardware designs were completed and the drawings were issued. The electrical schematic diagrams were started and will reflect both temporary and permanent instrumentation.

B. TEMPORARY INSTRUMENTATION

The specification control drawing for test stand thermocouples was completed and issued. Accelerometer cable drawings and accelerometer housing and mounting provision drawings were completed and issued. The electrical harness assembly drawings and mounting hardware drawings were completed. The temporary instrumentation installation drawing was completed.

2.5 GROUND OPERATIONS SAFETY

2.5.1 SAFETY ANALYSIS AND REVIEW

A. Programs

1. NRX-A3

Several safety evaluations and reviews of NRX-A3 operations were completed during this quarter. These included issuance of Supplement 2 to the NRX-A3 Safety Evaluation Report covering review of a number of Control experiments in the EP-IV test and review of control room operating procedures covering the NRX-A3 test operations. Based upon these safety evaluations and reviews, SNPO-C approvals of the NRX-A3 test operations were obtained.

2. NRX/EST

Preparation of the Safety Evaluation Report for the NRX/EST tests continued during this period and work on the Operating Limits document was initiated. Initial drafts of procedures covering receipt and assembly of NRX/EST at NRDS were reviewed.

3. ETS-1 Design Safety Evaluation

The preliminary safety evaluation of the design of the ETS-1 complex was continued through this quarter. Systems evaluated include the Process and Fluid System, Nuclear Exhaust Systems, Facility Instrumentation and Control System and Engine Compartment Radiation Shield. Preparation of a report has been initiated.

4. XE - Engine Program

The requirements for Emergency Cool-down for the XE-Engine were reviewed and it was concluded that Emergency Cool-down II (dome-end cooling with inert gas) could be dropped from further consideration without affecting the safety of operations.

The current status of the Engine Control System was reviewed in conjunction with the Test Stand Control System and the Engine Safety System. Safety Division coordination and inputs were supplied for the preparation of the XE-1 Functional Flow Charts.

5. Stcam Generator Development Test Program

Steam Generator Test Specifications and Checklists were reviewed for Tests EP-I through EP-III and NTO was authorized to initiate testing. Following review of Test Specification 003, the potential hazard associated with automatic start-up of the standby generator was noted and Supplement No. 1 to Test Specification 003 was issued deleting the requirement for automatic start-up.

B. FACILITIES

1. E-MAD Facility

Phase III of the E-MAD Shielding Integrity (SIC) testing was completed and all major shielding deficiencies were corrected. Phase II test procedures on post-mortem cells were reviewed and comments were incorporated in the final draft of test procedures.

2. NTO Operations

A safety audit of NTO Test Cell "A" operations during the EP-I phase of NRX-A3 test series was conducted on 6-8 April. The auditor's findings indicate that the procedures applicable to NRX-A3 Experimental Plan I, as implemented, adequately ensure the safety of the operation. No major deficiencies were noted.

A non-nuclear safety audit of NTO operations was conducted on 24 - 25 June. The audit was conducted to review the status of actions resulting from the recommendations of the 23 - 26 February 1965 audit.

3. Sacramento Operations

An inspection of the high-pressure gas tank farm at the REON Sacramento Instrumentation and Controls Laboratory revealed a number of safety deficiencies. Recommended corrective actions were initiated.

4. WANL Operations

A non-nuclear safety audit was conducted on the WANL Hydrogen Corrosion Facility and the WANL Hydrogen Experimental Site (WANHES) was conducted on 6 - 7 May. A number of recommendations were made to correct noted deficiencies. WANL has initiated corrective actions.

A radiological safety audit of WANL facilities was conducted on 11 - 12 May. No major deficiencies were noted.

5. NERVA Program Safety Record

No lost-time accidents, fire or other property damage losses, or radiation exposure incidents were recorded for NERVA Program activities during this period.

2.5.2 NRDS GROUND OPERATIONS SAFETY

A. MANAGEMENT

As stated in paragraph B,2 above, Test Cell "A" Operations were audited during the EP-I phase of the NRX-A3 Test Series by REON. The audit conclusions were stated to be satisfactory and no major deficiencies were noted.

The Nuclear Materials Management Accountability Station AEC (NTO) was audited by SNPO Cleveland and found to be satisfactory.

B. NRX-A3

The highest radiation exposure received during the EP testing was 50 mr, which occurred during removal of calibration wires from the core of the reactor.

Radiation exposure to in-cell working personnel preparing for NRX-A3 EP-V was effectively controlled by Test Cell "A" Management, although necessary work on the nozzle cover boom led to some personnel exposures in the 400-mr region.

Release of radioactivity from the EP-VI was somewhat higher than anticipated. No significant exposure to any on- or off-site personnel resulted from the test.

After EP-VI, Test Cell "A" was found to be moderately contaminated. NTO Health and Safety directed the decontamination of the Test Cell "A" pad after the test series. Radiation support for the NRX-A3 disconnect was provided.

C. ETS-1

NERVA Health and Safety personnel provided safety support during the tests on the Steam Generator System on ETS-1 (EP-I through the major portion of EP-II).

A steam generator plenum entry was made at ETS-1 on May 20 and May 21. All objectives in performing this entry were achieved without incidents.

An industrial safety inspection was made by SNPO-N and NTO Safety Personnel of the sub-contractor's operations in the pipe chase and duct vault areas at ETS-1. The observed discrepancies will be handled by SNPO-N with CATCO.

A conference was held between NTO Safety at ETS-1 and Pan Am Safety concerning techniques and methods of reporting unsafe acts or operations for early solution.

D. E-MAD

Procurement of Health Physics Instrumentation to be installed in the E-MAD (with the exception of the critically safety monitor and a radiation detector in the E-MAD guard house) was initiated. The locations of the air sampling heads for the house vacuum air sampling system have been specified.

Radiation monitoring equipment (Vitro package 3000) will be delivered by Tracerlab by July 16, 1965.

During the week of May 7 the State of Nevada Industrial Commission Department of Industrial Safety conducted an inspection on two boilers and two infired pressure vessels at the E-MAD. Several deficiencies were noted.

During the week of May 21 the first two of four emergency warden fire protection sessions were held. Demonstrations were made of fire extinguishers by the Fire Department and a film was shown on the same subject.

Arrangements were made for the NRDS Fire Department to inspect E-MAD constructions prior to welding and cutting operations to aid in fire prevention.

2.6 PRODUCT ASSURANCE

2.6.1 PRODUCT ASSURANCE - CONTRACTOR'S PLANTS

A. PRODUCT ASSURANCE DIVISION - REON

1. General

REON R&QA Program Plan Report No. 2487, Revision A, is now in publication and will be issued during July 1965.

In May 1965 internal audits were run to determine the capability of the Sacramento Support Operations to supply the necessary quality data to the Product Assurance Division REON. As a result of these audits, recommendations were made that the REON Product Assurance Division Data System be revised to make full use of the Sacramento Plant Support Operations capabilities.

Product Assurance REON is now developing trend charts covering the six major areas of

Fabrication Inspection Hydraulic Shop
Fabrication Inspection Assembly Shop
Receiving Inspection NERVA Program
Fabrication Inspection NERVA Machine Shop
Fabrication Inspection NERVA Weld Shop
Test Area Inspection

These charts will take into consideration the total parts inspected and the percent discrepant, and will enable the Product Assurance Division to make an analysis of the problem areas and see that corrective action is taken to eliminate the problems.

During this report period, PAD developed and implemented a Test Area Quality Control Plan, describing the activities determined necessary to

Provide assurance that the inherent reliability of engine and test support hardware is maintained during the test cycle, and

Provide the information necessary to more fully measure and control the quality of hardware for the NERVA Sacramento Test Program

This plan has been reviewed and approved by all necessary Sacramento Divisions.

2. Product Assurance Engineering

a. Turbopump

A new radiographic process for the determination of quality levels on the NERVA pump housing is now being reviewed. It is expected that this document will be published during the next reporting period.

Due to the cracking problem in the A-286 turbine rotors, a thorough NDT evaluation is being conducted. A check sheet, including the following forms of nondestructive testing, was established and the following tests were conducted:

Ultrasonics
Zyglo
Eddy Current
Residual Surface Stress
Hub Etching

As a result of these tests and their evaluation, improved acceptance criteria will be established.

b. U-Tube Nozzle

Continued development studies are still being conducted on the ultrasonic technique on an NRX-A configuration nozzle assembly, S/N 008. Samples of trepanning were subjected to ultrasonic correlation studies. It is planned to continue the correlation study during the next quarter.

Ultrasonic cleaning methods were used on the nozzle and were not successful in cleaning the inside passages. However, the cleaning standard, AGC-STD-9001, was successfully used for the nozzle components and during the major phases of assembly operations.

The technique of brazing the channels to the nozzle has been improved to a high level of reliability. The last few nozzles have had only three to six minor leaks. Improved quality of channels, the cleaning and preparation of nozzle surfaces, and improved dimensional control of nozzle grooves have all contributed to this improved brazing quality.

c. Test Stand Control System

In the last reporting period a quality assurance program plan for TSCS was prepared. This plan was approved and was primarily designed to satisfy the quality control objective specified in the Program Plan for Sub-task 2.2.8. The test procedures will be completed next quarter.

d. MCC/EIV

During this report period work was continued on the correction of inadequacies present in the MCC/EIV. When work was terminated at AMF and the unit shipped to Sacramento, tasks for initiation and completion were reviewed by the task team, consisting of four Project Engineering representatives and a Product Assurance Engineer. A total of approximately 30 tasks were completed during this quarter.

The MCC and EIV specifications have been reviewed and will be published during the next quarter, incorporating a number of changes.

e. Integrated Planning

REON Product Assurance Engineering is implementing integrated shop planning that is compatible with the development nature of the REON Program and will eliminate difficulties in tracing materials and making provisions for ICD call-outs on the planning.

Reviews have been conducted on 397 sets of integrated planning for component parts and assemblies, of which approximately 70% apply to the propellant feed line systems and the remaining to the nozzle hardware.

3. <u>Quality Assurance</u>

The shipment of NRX/EST instrumentation components to NTO required definition of materials for End Item Material Review Board review prior to release at NTO. This was accomplished by the issue of a memorandum coordinated with SNPO-C. To assure proper quality control, Product Assurance Engineering will approve all shipping instructions prior to release.

B. SUBCONTRACTOR AND PROCUREMENT CONTROL

1. Permanent Radiation Shield

REON Product Assurance coordination was performed with WEC (Sunnyvale), SNPO-C, NTO QC Representative, and Aetron/Covina Engineering regarding disposition of nonconforming material and documentation for the End Item Report or Log Book for the Permanent Radiation Shield. REON Product Assurance determined and reported the status of outstanding "G" letters to assure completion of disposition on nonconforming material.

2. Coordination with ACFI

SNPO-C presented the results of a survey trip by Mr. Dallas Adams to ACFI, Albuquerque, New Mexico. The purpose of the conference was to determine a method of operation with ACFI through AEC offices at Albuquerque to improve the Quality Control coverage of articles being furnished by ACFI for SNPO-C, WANL and AGC. It was concluded that the activity issuing the procurement to ACFI would clearly delineate QC provisions in the Procurement Package and request AEC to provide QE services, QC coverage and monitoring of ACFI. ACFI would be requested in the Procurement Package to develop and present inspection plans and procedures, the necessary process control procedures, and special inspection process control procedures, together with shop drawings for approval by the activity issuing the procurement. The issuing activity (in the case of WANL or AGC) would only be permitted to perform source surveillance at ACFI through a direct request to SNPO-C, Mr. J. Dutli, or to visit ACFI only in the company of a SNPO-C representative; Mr. D. Adams was designated as the SNPO-C representative responsible for this liaison when available; where necessary Mr. Dutli would provide an alternate guide in those cases where Mr. Adams could not be available. It was concluded that this approach should greatly improve the quality control coverage of the articles being supplied by ACFI. The procedure was agreed to by WANL and AGC.

3. Procurement Control

REON Product Assurance Procurement Control supported an increased procurement activity during this reporting period.

In the last quarterly report it was pointed out that Procurement Control was establishing control points at the source of manufacture and directing the source verification effort in order to receive quality hardware. The advantages of establishing control points at the source of manufacture and directing the source verification effort has resulted in improvement in quality and configuration control by directing attention to the planning and the early detection of potential problems or conformances, and the early detection of nonconformances, and reporting them on Supplier Discrepancy Action Requests (SDARs). More accurate and complete documentation from suppliers is also evident.

2.6.2 QUALITY ASSURANCE - NRDS

A. R-MAD

During this reporting period the NTO Quality Control organization has had minor reorganization with major physical relocation of Quality Control personnel. Quality Control personnel have been assigned and are now located at the Control Point, ETS-1, and R-MAD in accordance with the task requirements. The objective of this decentralization is to allow each area supervisor to operate reasonably independent of the other areas with the personnel available.

The R-MAD Quality Control activities for the past quarter have been concerned with the NRX-A3 assembly, disassembly, and post-operative examination operations and the ACFI NRX-EST Test Car. Subsequent to the completion of the NRX-A3 assembly, NTO Quality Control issued a QRDR Summary Report and an analysis of the summary. Analysis of the discrepancies or failures reported on the NRX-A3 assembly operations indicated approximately 32% of the items reported were related to erroneous or incomplete information on drawings, wiring schedules, and procedures. In most instances, discrepancies were of a minor nature. 24% of the discrepancies reported were items classified as design problems. Receiving Inspection accounted for 24% of discrepancies. This category relates to lack of proper documentation and certifications upon receipt at NRDS. QRDRs categorized as "information only" type of discrepancies were those documents which were written to record requirements for improvements or information. These accounted for 11% of the total. 9% of the discrepancies were attributed directly to personnel errors and carelessness.

A process capability study of the Actuator Controls System was initiated by NTO Quality Control. The results of this study have not been completed because of several anomalies in the data traces, which were attributed to equipment and operator error and do not provide conclusive results. A retest is scheduled after the test equipment has been repaired and operators have been properly trained. Currently, a series of audits is being conducted on NRX/EST hardware. These audits affect ACFI- and NTO-received hardware. Periodic audit reports on the NRX/EST hardware and Test Car will be issued as they are completed.

B. CONTROL POINT AND TEST CELL "A"

NTO Quality Control has prepared an Electrical Workmanship Standard for use at NRDS which is specifically applicable to Test Cell "A".

During the NRX-A3 test series, Quality Control personnel recorded all discrepancies during R-2, R-1, and Run Day to establish a basis for notating discrepancies. Any abnormality occurring during these test activities would be classified as a discrepancy. A summary report has been prepared of these discrepancies, which includes the disposition and corrective action taken by the operating groups. Discrepancies fall into two categories: equipment failure and personnel error. Of these two categories, 29 were noted as equipment failure and 21 as personnel errors. The temporary personnel assigned to NTO Quality Control from WANL, Large, have been participating in the preparation of the Workmanship Standards and analyses of Control Point and Test Cell "A" operations.

C. ETS-1, E-MAD RECEIVING AND SHIPPING

NTO Quality Control activity at ETS-1 has been concerned with the Steam Generator System testing program and a nominal effort in the electrical installation area. All discrepant conditions relating to the Steam Generator tests were noted on QRDRs and are awaiting disposition by REON Development Engineering.

The Miscellaneous Craft Work Audit System was re-established at ETS-1. Operating personnel are preparing specific instruction to craft workers for activities requiring special attention. NTO Quality Control has participated in the review of installation plans for the NES Duct System and Side Shields. During this last report period, NTO Quality Control has prepared rough drafts of plans for Quality Control surveillance of E-MAD systems installations. It is currently Quality Control's plan to witness all final acceptance tests.

In the areas of Quality Control Support, which includes shipping, receiving, procedures, and calibration of tools, NTO Quality Control activities have been concerned with receipt of NRX/EST hardware, calibration of tools, and instructions. All tools and gages were calibrated prior to NRX-A3 disassembly operations. A standard torque procedure has been prepared by Quality Control and submitted for review and issuance as a NTO Standard Operating Procedure. During the next quarter NTO Quality Control anticipates clarifying the Support Services Contractor (SSC) responsibilities.

D. COORDINATION OF ACTIVITIES

Quality Control personnel have been actively engaged in several off-site and on-site meetings having to do with EG&G activity at Test Cell "A" and the Control Point, ACFI Quality Control activity at Albuquerque, and Cleanliness Committee meetings.

2.8 NON-FUEL MATERIALS

2.8.0 PLANNING AND COORDINATION

Two investigations were developed for Contract Year 1966: one concerning effects of materials irradiation, and the other relating to turbopump bearing materials.

A. MATERIALS RADIATION EFFECTS PROGRAM

Requirements for three materials irradiation tests have been established for CH '66. The first test (designated as GTR-18) is to be performed as early as possible in CY 1966 to qualify the thermal conductivity test cells, and to determine the effectiveness of helium convection cooling in preventing overheating from gamma radiation in low conductivity materials.

Need has been established for a second test (GRR-19) which is planned for structural materials at higher dose levels, and will include additional metals for irradiation at -423°F. Ambient irradiations are to be performed in boron containing materials, the high-temperature properties of which are suspected to be affected by the presence of helium resulting from the thermal neutron (n,) reaction with boron.

The third test (GTR-20) is needed to measure cryogenic ductilities of critical pump and nozzle materials at a dose level about a decade higher than was used in GTR-15). Test temperatures of both -320°F and -423°F are to be used.

B. TURBOPUMP BEARING MATERIALS PROGRAM

The first objective in upgrading bearing performance is the replacement of radiation-limited organic retainers by metal.

The second objective is substitution of a tougher face-centered-cubic alloy for the brittle, impact sensitive type 440-C stainless steel now in use for rolling elements. Several candidate materials are under consideration. The program will consist of two phases: the development of hard surfaced material with good cryogenic mechanical properties, and the fabrication of test bearings and conducting NERVA type performance tests in liquid hydrogen.

Other Materials activities supporting the Turbopump Component Development (Subtask 1.2.3), the Nozzle Development Program (Subtask 1.4), the Propellant Feed System (Subtask 1.2), and the Radiation Effects (Subtask 1.9) are included under the corresponding subtask.

2.8.1 MATERIALS AND PROCEDURES

A. GTR-16 TEST RESULTS

This investigation measured the tensile and shear properties of several NERVA alloys which were irradiated to a dose of about 10^{17} nvt (fast) at -420°F and tested prior to warmup. The most significant results are:

Ultimate Shear Strength - Since only minor changes occurred in this property, none were large enough to be of design significance.

Ultimate Tensile Strength (unnotched) - Only two alloys, Inconel 713-cast and A-110-AT, changed strength in excess of normal variations in properties. Inconel 713-C increased from 112 to 133 ksi; A-110-AT increased from 216 to 226 ksi.

Ultimate Strength (notched specimens) - One alloy significantly increased in strength. Al 6061-T6, longitudinally welded and reheat treated to the T-6 condition, increased from 54.2 to 69.8 ksi. Titanium A-110-AT decreased its notch strength from 171.0 to 153.7 ksi.

Yield Strength - Appreciable increases in yield strength were noted in several alloys, as tabulated below:

TABLE 6

INCREASES OF YIELD STRENGTH BY CRYOGENIC IRRADIATION

A356	ksi pre-irradiated control	ksi post irradiated	ksi change
A-356-T6	31.0	46.9	15.9
6061-T6	46.5	56.5	10.0
6061-T6 (Transverse Welded)	39.1	60.3	21.2
7075-T6	94.9	106.6	11.7
Inconel X-750	135.8	151.8	16.0

Elongation and Reduction in Area - Decreases of elongation occurred in all alloys; however, these data will require corrections for plastic strain outside of the gage section. These corrections will probably decrease the apparent radiation effects. In any event, none of the changes in the ductile alloys are sufficient to be of concern to engineering design. The low ductility alloys, on the other hand, appear to be affected sufficiently to require careful consideration by designers. These data are tabulated below in Table 7.

TABLE 7

Material	Elongation Pre-Irrad.	Elongation Post Irrad.	Area Reduction % Pre-Irrad.	Area Reduction % Post Irrad.
Hastelloy C	39.2	37.9	32.6	32.7
347	40.2	35.0	28.0	27.9
A-286	37.5	26.5	31.0	32.1
347 Welded	27.1	28.2	20.8	23.6
Inconel X	31.2	26.4	27.1	26.6
6061-T6	24.1	18.1	32.4	32.6
A-110-AT	18.5	13.0	17.8	16.8
6061-T6, TWU	9.0	7.3	16.4	21.6
Type 347-C, cast	7.7	7.3	8.8	6.4
6061-T6, LWU	6.0	5.5	11.9	10.8
A-110-AT, TWU	5.9	4.8	9.4	11.4
7075-T6	6.4	4.1	7.0	7.9
A-356, cast	1.5	2.0	2.8	0.8
Inconel 713, cast	3.0	1.8	7.0	1.7
440-C	0	0	-	-

TWU - Transverse welded, unnotched
LWU - Longitudinal welded, unnotched

This test demonstrated that most alloys evaluated can be used safely in a combined liquid hydrogen nuclear radiation environment at dose levels of 10^{17} nvt. A few alloys, which initially have marginal ductilities, are further degraded by irradiation. These include cast and welded alloys, and their use in this environment should be avoided.

B. POLYFOAM TUBE PROTECTION

A fire-resistant polyurethane foam was applied after brazing to the interior of NERVA nozzles S/N 021, 024, and 026 to protect U-tubes from damage during fabrication and handling. The current technique utilizes spraying instead of casting in place, as on previous nozzles.

2.8.3 REPORTING OF MATERIALS DATA

During this quarter the 1st 1965 semi-annual supplement to the Materials Data Book was published. A development plan was formulated for the Data Book revision to be published in January 1966. A Data Book style guide was prepared for this and provides for a totally new, more compact format. This document will facilitate and reduce the cost of Data Book master sheet preparation.

Pages 204, 205 and 206 have purposely been omitted.

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SECTION III (CONTINUED)

TECHNICAL DISCUSSION
TASK 3

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3.1 NERVA EXHAUST SYSTEM (NES)

3.1.3 SCALE MODEL PROGRAM

A. GENERAL

The scale model testing is completed and the data are being analyzed. The preliminary test results and initial data analysis were presented to representatives of SNPO-C on 17 June 1965.

B. SECONDARY EJECTOR SYSTEM

The secondary ejector tests were completed on 10 June 1965 with the running of test D-284-LQ-52. The test hardware is shown in Figures 50 and 51. Altogether 27 tests were completed in Phase I, 13 tests in Phase II and 12 in Phase III.

A set of all the reduced data for the 52 tests has been forwarded to Dr. Jerry Grey of Princeton University for use in checking his analyses and predictions. Dr. Grey is responsible for analysis of the mixing data generated in Phase II.

Preliminary results of Phase I and III show that for each value of Ω tested there is a specific point during the test at which the primary exit Mach number becomes constant. This phenomenon could be caused by a choking condition in the secondary duct. Whatever the reason, performance of the system suffers when operating in the constant Mach number region. Ability to predict the point of constant Mach number will constitute a major portion of work remaining in the CY 65 Program.

C. CENTER BODY DIFFUSERS

Twenty-four tests were conducted on the center body diffuser. The exterior view of the test hardware is shown in Figure 52. The final test, D-285-LQ-24, was run on 25 June 1965. The first 12 tests (6 heat transfer and 6 gas dynamic) indicated lower than expected heat-transfer rates to the nosepiece of the center body.

To ensure a minimum of heat loss to the interior of the center body, the remaining three nosepieces were completely insulated with Vermiculite. The tests conducted with these nosepieces indicate a closer agreement between theory and test data. It was decided to rerun the heat transfer portion of the tests on the first six nosepieces. The results of these tests are currently being analyzed.

On Run D-285-LQ-19, a calorimeter was installed in nosepiece 1.58-30° and a heat-transfer test was conducted, data from which are presently being reduced. The oscillograph record shows that the ΔT (or the heat-transfer rate of the calorimeter) reacts to the large pressure fluctuations at the exit of the 40:1 contoured nozzle during engine shut-down. This phenomenon perhaps indicates that the shock waves set up when the 40:1 nozzle is not flowing full are contacting the nosepiece of the center body. Analysis of both gas dynamic and heat transfer data is continuing.

(Text continued on page 412)

Figure 50

Pumping Studies Test Hardware

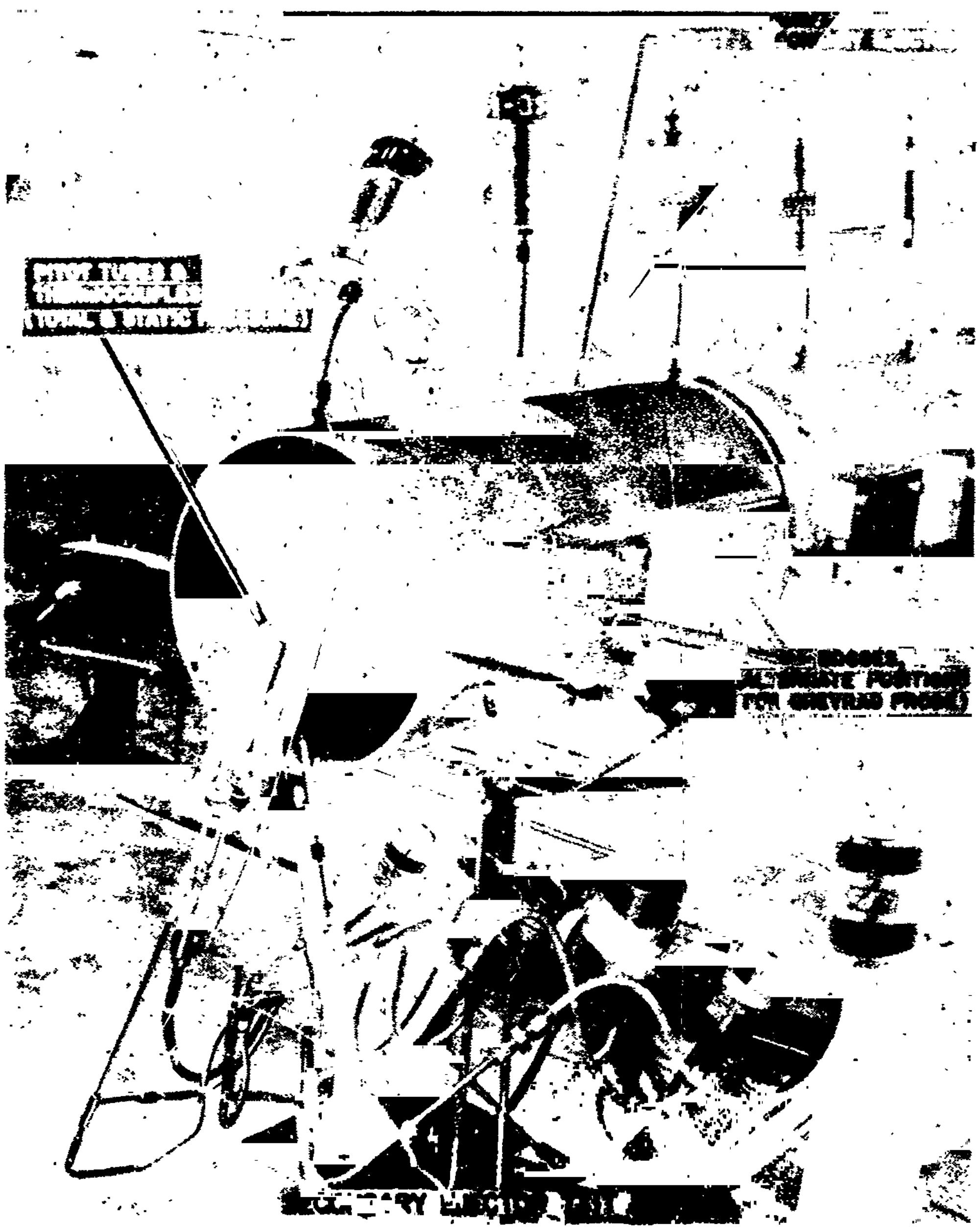

Figure 51

Secondary Ejector Exit

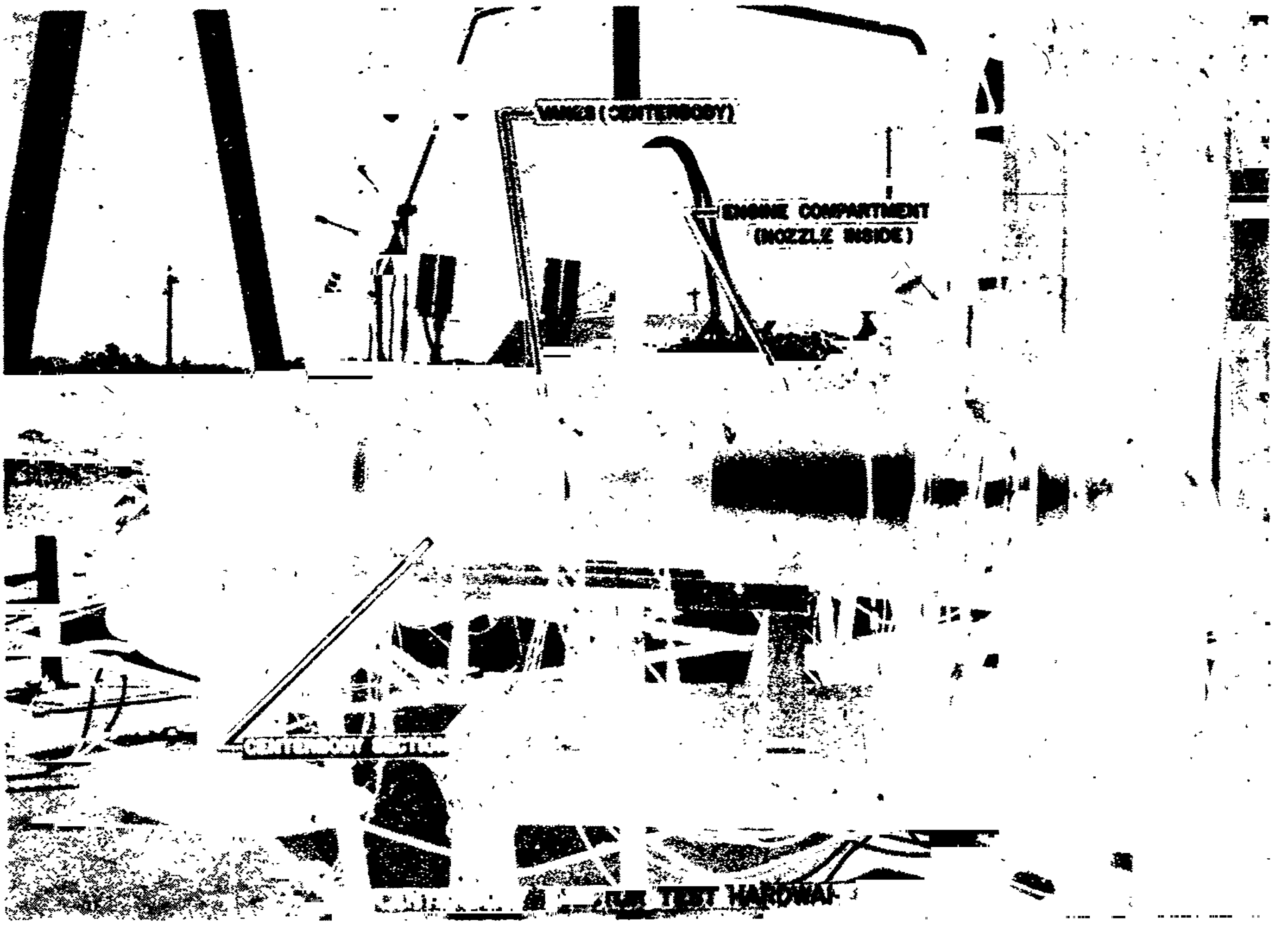

Figure 52

Centerbody Ejector Test Hardware

3.1.4 EXHAUST SYSTEM ETS-1

A. DUCT

1. Fabrication

REON personnel participate in the NES duct fabrication status review meetings held at the Air Preheater Company, Wellsville, New York to discuss fabrication progress. The agenda has included design, fabrication, schedules, and weld, stress relief, assembly, and installation procedures.

The inner shell of the primary duct section, as received by the Air Preheater Company from the Excelco Company, Silver Creek, New York, is shown in Figures 53, 54, and 55. Attachment of coolant flow angles to the primary duct section is shown in Figure 56. Attachment of coolant flow angles to the 45° exit elbow is shown in Figures 57 and 58. Coolant flow angles are being fitted and welded to the primary duct section and to the 45° exit elbow of the secondary duct section. Some slight distortions due to welding operations have occurred, but no serious problems have been encountered.

Welding operations on the secondary steam ejector manifold were completed. Figures 59 and 60 show the steam ejector and the stress relieving furnace thermocouple survey fixture prior to stress relieving at the Pfaulder Company, Rochester, New York.

The two halves of the 90° duct elbow have been mated in the weld fixture. The weldment joining of the two halves is in process as shown in Figure 61.

Internal casts made of the inside surfaces of tubes in the elbow section have given accurate measurements of defective areas resulting from welding operations.

2. Source Surveillance

Source surveillance has continued on the West Coast for all subcontractors to the Air Preheater Company. These subcontractors include the Palmer Company, Whittier, California; Marman/Aeroquip Corporation, Los Angeles, California; and the Cromer Manufacturing Company, Los Angeles, California.

<u>The Palmer Company</u> - The Palmer Company was given a contract by the Air Preheater Company for fabrication of nine small bellows for use with installation of thermocouple wells in the duct elbow water jacket. This contract has been completed.

<u>Marman/Aeroquip Corporation</u> - With the exception of the pneumatic actuator assemblies, fabrication of all hardware for the steam-line-severance plane joint assembly is completed. Rework associated with a change from non-metallic to metallic vanes is required on the actuators. With the completion of this rework, an acceptance test is planned to demonstrate unit performance.

All fabrication on the duct severance plane joint assembly has been completed. Seal leakage tests will be performed before final acceptance.

Hardware fabrication for the water inlet and water outlet severance plane joint assemblies is approximately 60% completed. Completion is anticipated during the next report period.

<u>Cromer Manufacturing Company</u> - With the exception of the 57001 and 57002 shroud assemblies, all work at the Cromer Manufacturing Company is completed. Completion of the shroud assemblies has been delayed because of die breakage. It is anticipated that these assemblies will be completed during the next report period. As presently planned, this delay will have no adverse effect on duct fabrication schedules.

(Text continued on page [illegible])

Figure 53

NES Duct Primary Section
Inner Shell, Top View

Figure 54

NES Duct Primary Section

Inner Shell, Side View

Figure 55

NES Duct Primary Section
Inner Shell, Front View

Figure 56

Attachment of Coolant Angles

Primary Shell

Figure 57

Attachment of Coolant Angles
45° Exit Elbow

Figure 58

Attachment of Coolant Angles
45° Exit Elbow
(Close-up view)

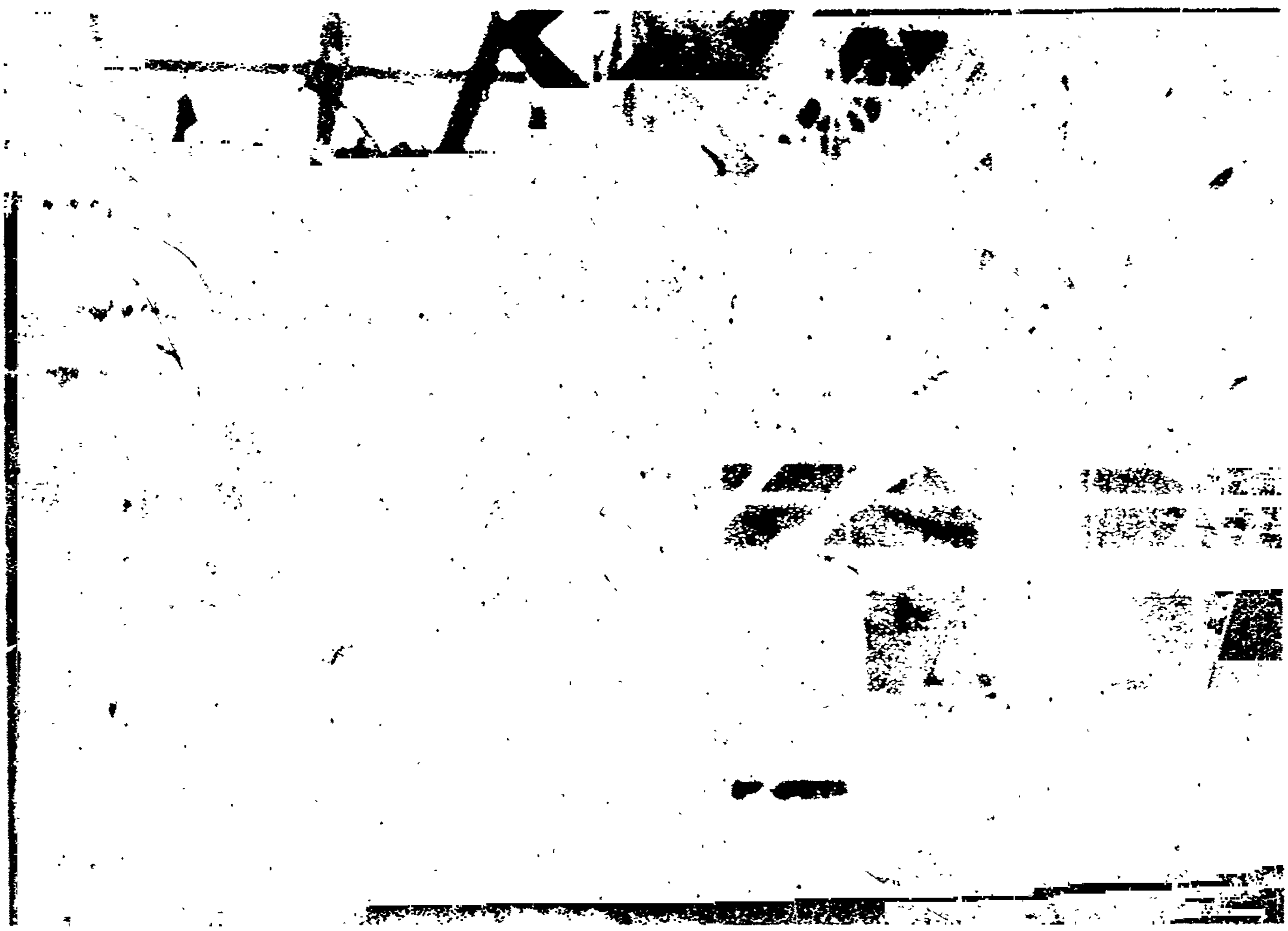

Figure 59

Steam Ejector and Thermocouple

Survey Fixture

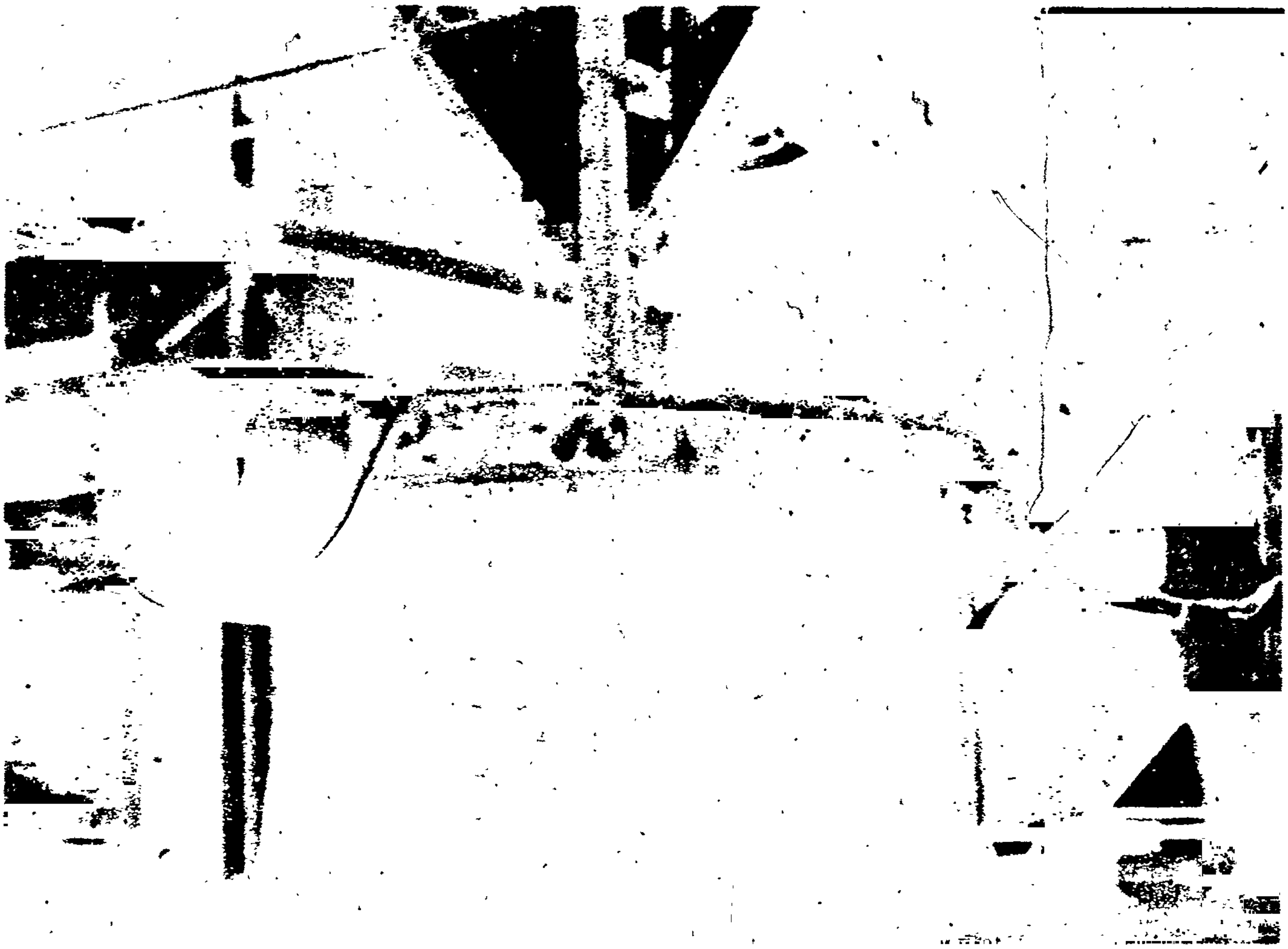

Figure 60

Steam Ejector
on Stress Relieving Fixture

Figure 61

Welding 90° Duct Angle

3.1.5 STEAM GENERATOR DEVELOPMENT

A. INITIAL SHAKE-DOWN TESTS AT ETS-1

Following installation and checkout of the system the following hot-firing tests, which are delineated in RN-S-0203, Steam Generator Test Plan, NES were conducted during this quarter on each of three generators:

Ignition and Idle Tests - To demonstrate satisfactory ignition and functional integrity of related instrumentation and controls.

Full Steam Tests - Short duration runs of 30 seconds maximum were conducted on each module with no attempt to adjust temperature (water control valve full on-board). All tests were considered satisfactory.

B. HARDWARE INSPECTION

Following the foregoing tests, the steam exhaust test pipe was removed, and the plenum inner liner and generator walls were visually inspected for damage or erosion. No erosion was detected and there was no indication of hot core impingement at the plenum elbow sections. However, upon removal of the main injector assembly of each generator, several weld cracks were observed on S/N 0016, as shown on Figures 62 and 63. An inspection was made of the injector assembly of the spare generator, which had previously been utilized to conduct the "Safety and Malfunction" test program. Although no weld cracks were present, the second-stage igniter had been severely damaged by excess temperature, as shown in Figure 64. It was also noted that the chamber inner liner had "blistered" in several places, although there was no indication of rupture or weld fracture. An immediate review of the safety and malfunction test data revealed that the system water shut-off valve had closed prior to shut-down while operating at full steam. This condition had previously gone undetected since all other data appeared normal. It has been tentatively concluded that the igniter failure and blistered chamber of the spare generator occurred because of loss of water during the final test of the safety and malfunction test program conducted at Thiokol Chemical Corporation

Thiokol is presently investigating this problem but has yet to concur with REON findings.

C. SPARES PROCUREMENT

One each of the following long-lead-time spare parts were fabricated by Thiokol:

Combustion Chamber	Injector Assembly
Plenum Assembly	Miscellaneous Filter Elements

Of the above spares, the plenum assembly was rejected during MRB because of weld cracks and other weld defects. Thiokol was advised to submit a repair procedure and correct the noted deficiencies. All other components have been delivered to NRDS.

(Text continued on page 230)

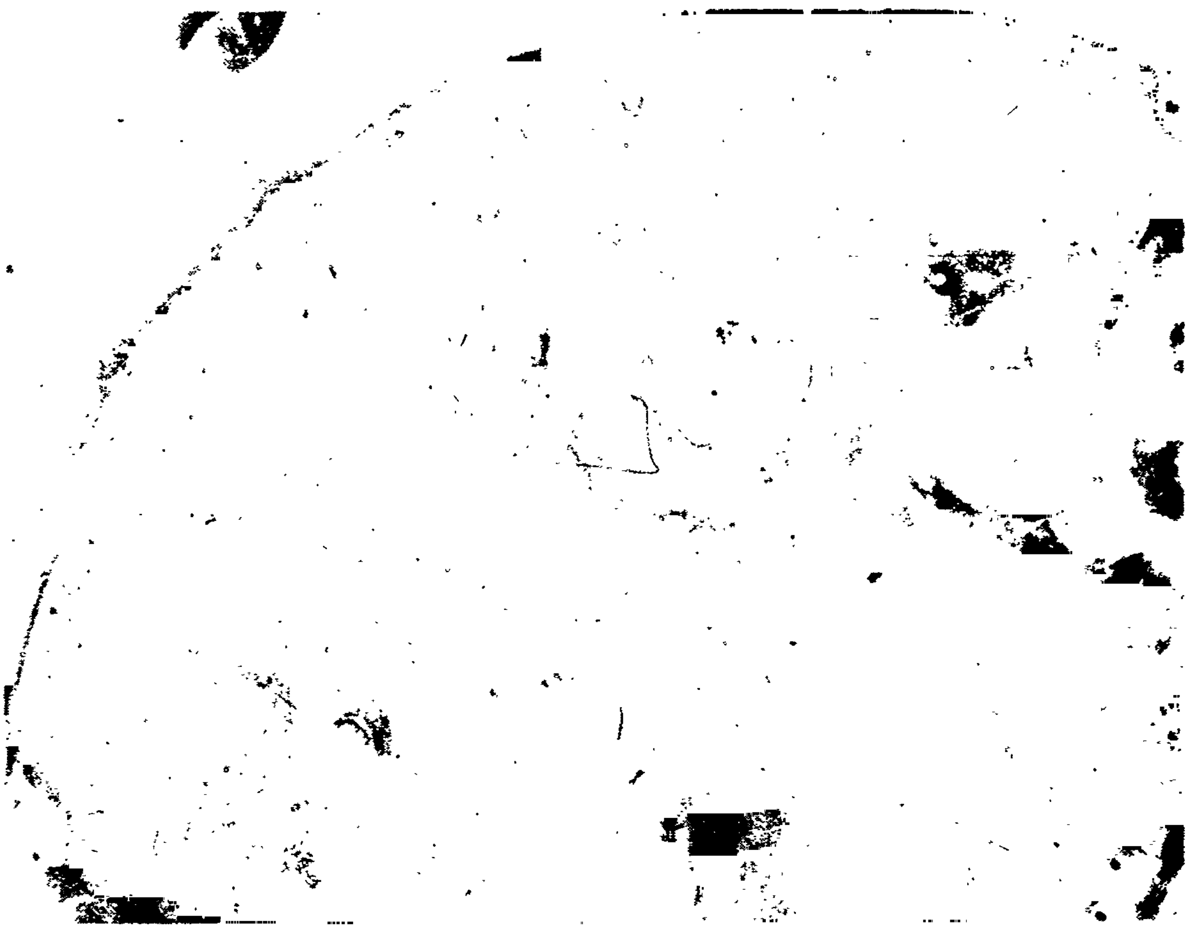

Figure 62

Injector Assembly, S/N 0016

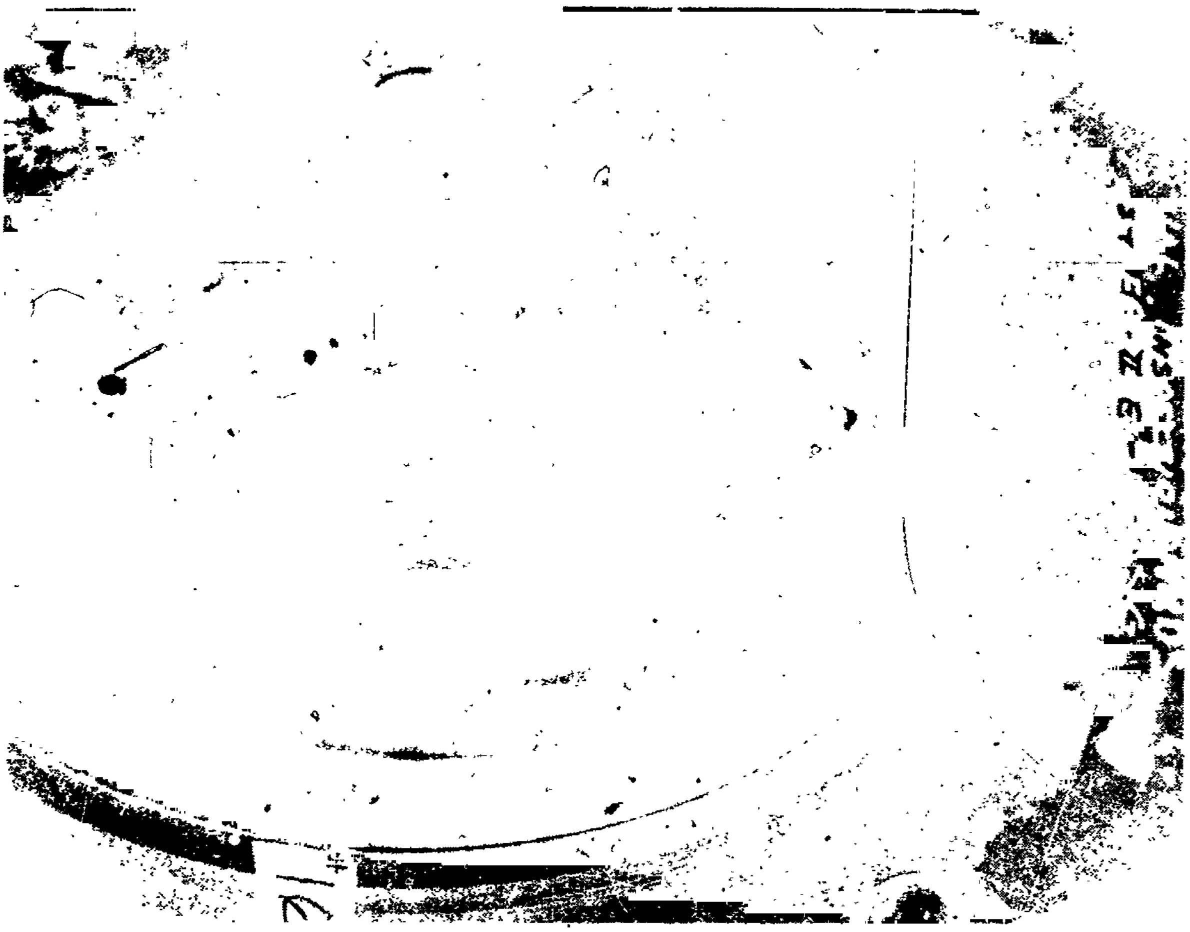

Figure 63

Injector Assembly, S/N 0016
Showing Weld Crack

Figure 64

Burned out Igniter Assembly, S/N 0019

3.1.8 GENERAL EXHAUST SYSTEM SUPPORT

A. FULL-SCALE DUCT FACILITY SEAL DEVELOPMENT PROGRAM

Fabrication of all hardware for the seal development program has been completed, with the exception of the pneumatic actuators. Rework associated with a change from non-metallic to metallic vanes is required on the actuators. Seal tests to date have confirmed the sealing capabilities of the joint.

The clamp and flange assembly is shown in Figure 65. The lower flange is shown in Figure 66.

A second duct-to-facility bellows assembly is being fabricated at Solar Aircraft Company, San Diego, California. Some warpage has occurred in welding the bottom flange to the bellows. A stress relieving operation after welding is planned as a corrective measure.

B. DESIGN DEMONSTRATION TEST PROGRAM

A proposal from the Annin Valve Company to provide the 12-inch pressure control valve was reviewed and found satisfactory. An inquiry is presently under way to determine the feasibility of having Annin supply the controller for this valve.

Fabrication was started of the 10 to 1 area ratio conical nozzle for the design demonstration test program

A preliminary edition of Revision A to REON Report RN-S-0137 NES Design Demonstration Test Program has been issued for review and comment.

C. DUCT INSTRUMENTATION

All drawings for the temporary instrumentation system have been reviewed and approved All mounting bracket drawings for the permanent instrumentation have been reviewed and approved. Installation drawings are approximately 50% completed.

The duct instrumentation cable boom fabricated by the LaMesa Tool Company, El Cajon, California, has been completed. The boom is shown in Figure 67 and 68.

A procedure defining location and orientation of all transducers on the NES duct has been completed.

D. OPERATIONAL AND SAFETY REQUIREMENTS AND DUCT INSTALLATION

Studies on emergency shut-down procedures made by REON indicate that a sufficient amount of H_2 could be expelled into the vault in case of a duct wall failure to result in a stoichionetric mixture with air regardless of the type of shut-down employed. Based on this study, it was concluded that the Emergency II shut-down is of no value in the event of a duct wall failure.

Flow tests were conducted on the duct flow tube specimen fabricated by the Palmer Company for REON. The data analysis shows a 2.6 velocity head loss from the tube exit to the "fold-back." A 2.0 velocity head loss was used for the duct design calculations.

A re-evaluation of the pressure drop across the duct was made using the higher tube exit loss and considering the modified ETS-1 process water system. Balancing orifices to be used in the duct were sized based on the results of this analysis. Flow testing of the duct tubes is shown in Figure 69.

Recommended changes to the duct vent and drain lines have been completed. These changes are proposed to reduce the number of ports to be sealed during proof and leak testing and to effect a flow reduction to conserve water during engine cooldown period.

The duct installation procedure from the Air Preheater Company was reviewed by REON and approval was transmitted to SNPO-C.

(Text continued on page 237)

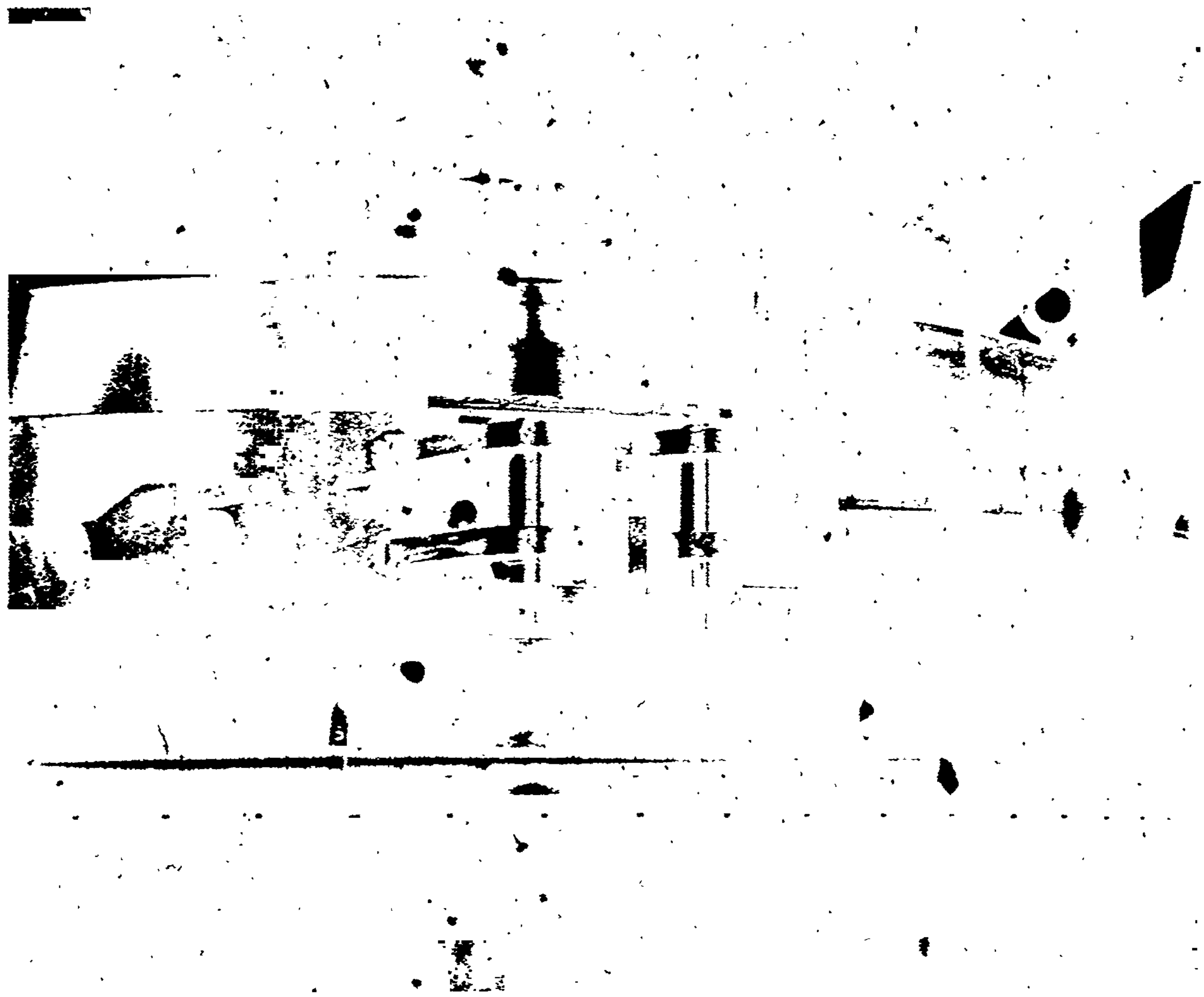

Figure 65

87-in. Marman Flange Coupling and Screw Jacks

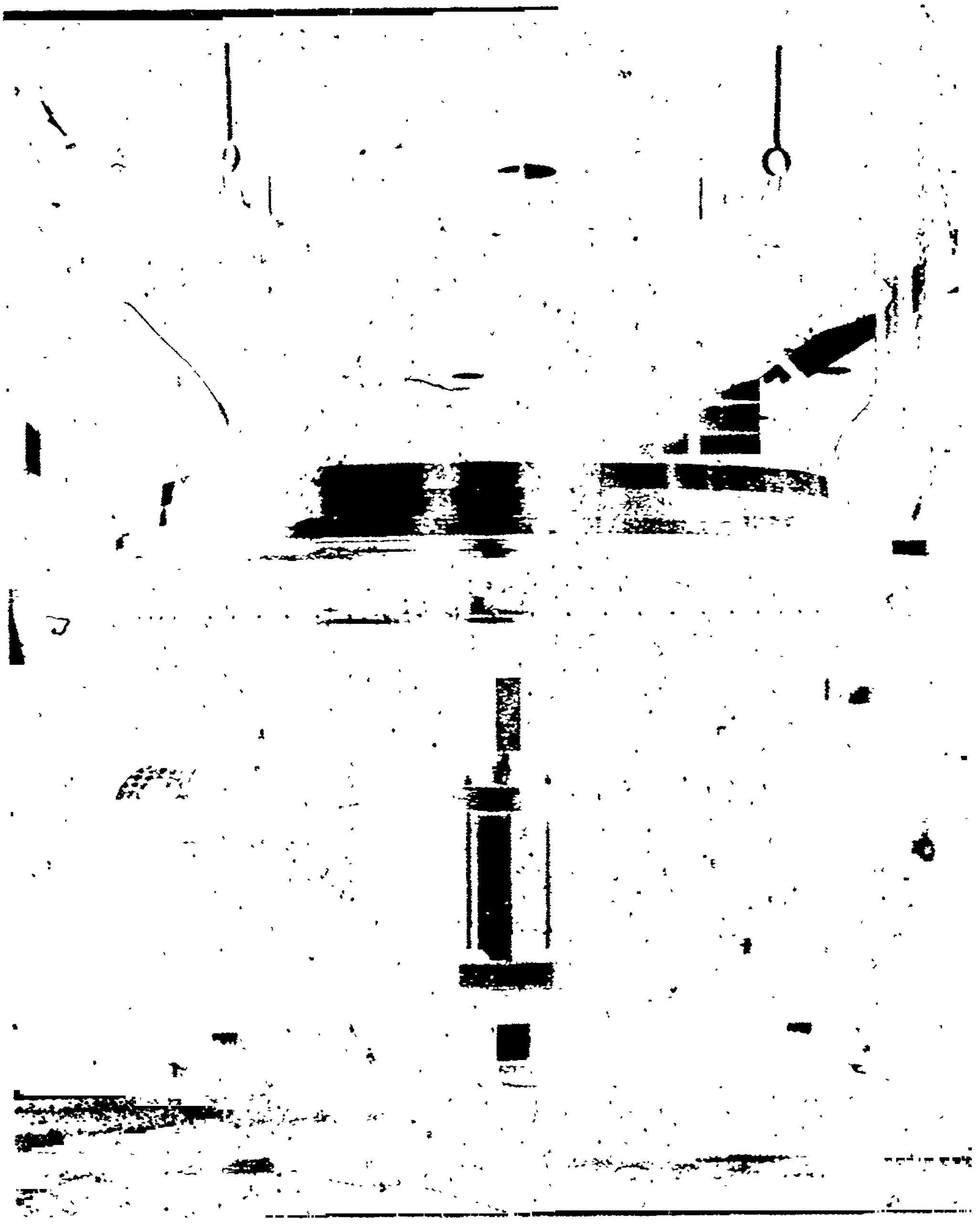

Figure 66

87-in. Marman Flange

Test Set-up

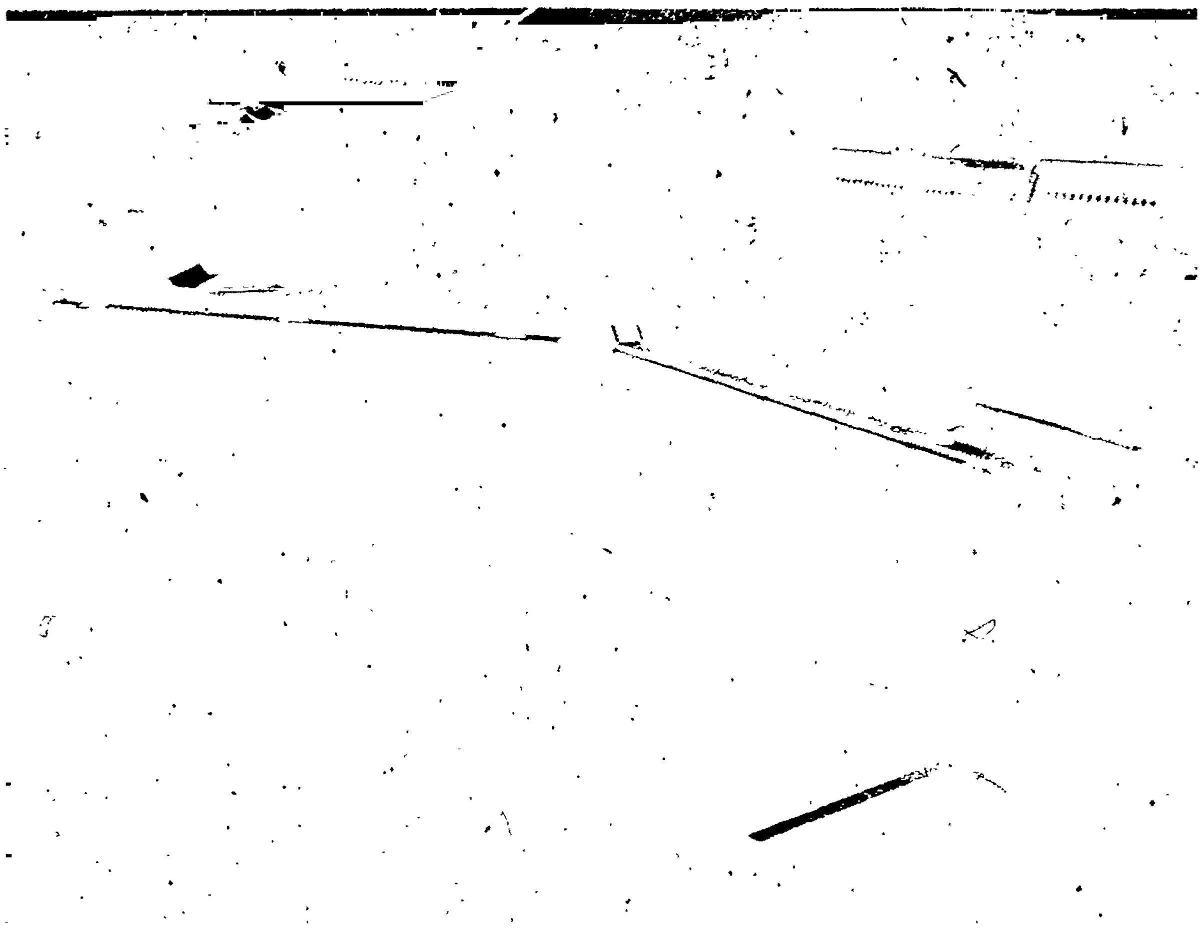

Figure 67

NES Duct Instrumentation Boom

Front View

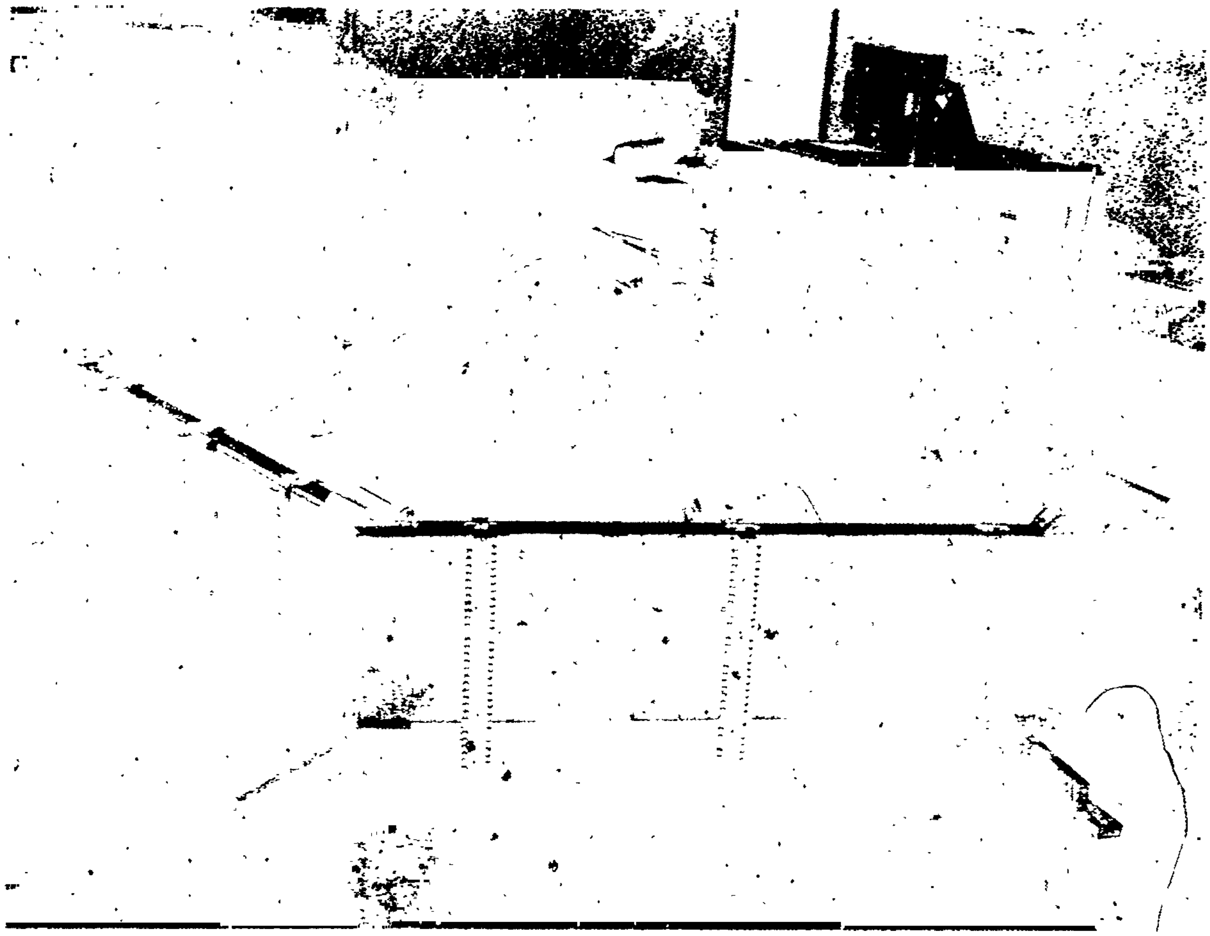

Figure 68

NES Duct Instrumentation Boom

Rear View

Figure 69

ES Duct Foldback Tube

Test Fixture

3.2 ETS-1

3.2.0 INTEGRATION AND TECHNICAL MANAGEMENT

The conduct of technical coordination, planning, subtask integration, liaison, technical direction, and overall integrated management continued in support of the development and activation of the ETS-1 Facility Complex consistent with the requirements of the NERVA program.

Facility systems data were updated to provide for each X-Engine cool-down schedule proposed and all engine requirements were reviewed to determine compatibility with existing or planned facilities. Facility capability and modification and proposed design alternates were incorporated in ETS-1 planning to allow establishment of engine requirements which would require minimal facility changes.

3.2.1 DESIGN REVIEW

Reviews of specifications for functional, operational, and safety adequacy to support the NERVA program were conducted, as well as reviews of A&E designs and construction drawings.

Continued evaluations were conducted (and transmitted to SNPO-C as required) regarding engine development changes and facility requirement changes. These efforts included the following:

The total facility cool-down capability was re-evaluated based on the latest XE-1 cool-down requirements and a report based on this analysis was published.

A study was continued, and design revisions initiated, to integrate all facility, electrical, and instrumentation purging systems and to determine their fluid requirements, but with utilization of air rather than an inert gas as the purge fluid wherever safe practices permit.

Design reviews of the Engine Test Compartment (ETC) shield package were conducted at the vendor's facility on a continuing basis.

Final design changes and test analysis of eutectic trough heating elements and gate were completed. A final test analysis will be subsequently reported.

Acceptance testing was conducted on the top seal bellows which has been accepted and is presently in transit to NRDS.

Piping design efforts are in progress in the ETC oxygen and other gas analyzing systems for the Engine Test Compartment.

A preliminary review of penetration ports and piping requirements in the ETC side shields was conducted to allow the passing of a known radiation source through the shields to check neutronic instrumentation.

3.2.2 NES FACILITY MODIFICATION

NTO engineering support was provided for the integration of the NES, the NES Steam Generator System, the NES support equipment required, and the NES checkout, in conjunction with the construction, activation, and checkout of the ETS-1 Facility Complex.

Engineering support continued, to determine a method to extend the duration of the pre-fire Engine Test Compartment purge. To accomplish the extended duration, a preliminary design concept was completed for a door which could be attached to the duct outlet. This door would provide a means of maintaining the required positive pressure in the ETC during the Purge period.

An analysis of ETS-1 cool-down systems is being continued to determine the compatibility of system capabilities with flow requirements of the integrated NES tests. Based on total utilization of the cooldown systems, it is anticipated that only minor modifications will be required to adapt from the NES integrated test program to the XE cooldown systems schedules.

Calculations and a summary were prepared in an investigation of the Pressure Control Valve (50-PCV-449) for the NES Demonstration Test with various size (6 to 12-in.-dia) combinations of parallel lines. It was disclosed that the effect of the reduced valve size on the GHe Cool-down II Schedule is negligible, but would improve the cool-down characteristics. Reduction of the valve size and addition of a 10 or 12-in. transmission line (as required by other systems) to the NES Demonstration Test System, increases the system capability.

3.2.3 INTERFACE/INTEGRATION AND CONTROL

Work was continued to prepare interface criteria, interface control drawings, and conduct preliminary design studies to define and integrate facility-to-facility interfaces and provide data for facility-to-test article interfaces. Studies continued to define the inter-relations and interfaces between the Test Stand Control System, the Instrumentation and Control System, all mechanical and flow facility systems and the XE-Engine. Assistance was provided in the generation and coordination of interfacing efforts in the preparation of the REON drawings for Installation and Interface Control, XE-1 Engine to the Engine Test Compartment.

A total composite flow schematic of the ETS-1 Facility has been initiated. As-built conditions of existing systems and the most current design of those systems proposed are being used as the basis for this as-built schematic.

A review of the thrust structure and electrical and fluid interface systems is continuing. Close coordination is being maintained with the engine and engine adapter interface requirements to assure compatibility with current requirements.

A system of Engineering Change Requests and Drawing Change Requests was initiated to fulfill the need for up-to-date facility as-built drawings control and the requirement for Engineering Change coordination and central approval. A component identification tag system was also initiated to replace the present field sketch procedure.

3.2.4 FACILITY-TO-THRUST-STRUCTURE SYSTEMS DEVELOPMENT

Thermodynamic, fluid, operations, and safety systems analysis required by changes in the NERVA engine requirements, as well as criteria, preliminary design, and procurement specifications engineering support were provided.

System design backup and analysis generated or revised on the basis of the latest X-Engine requirements include the following:

> Studies continued on available facility fluid storage capacity and curves of pressure drop as a function of flow rate. These studies are being updated for each proposed cool-down and alternate facility interface fluid supply system. Evaluation of system response time to assure engine and facility safety are in progress, as are analyses of fluid and system requirements to maintain an adequate fluid storage supply.
>
> Calculations are in progress to interpret the He line and supply requirements for two cool-down schedules and NES integrated test requirements. The results of these calculations and recommendations were transmitted to SNPO-C.

Coordination meetings were held in Cleveland to schedule Interface Systems procurement and installations consistent with ETS-1 actuation requirements. A subsequent 28 May meeting resulted in these decisions: There will be no Emergency II Cool-down line in the ETC intermediate shield. Appropriate revisions to the Interface System design and procurement were made as a direct result of these decisions.

Vendor and fabricator contacts continued in an effort to minimize fabrication and procurement lead times and to produce satisfactory components. Procurement for the Interface System piping components and fabricated materials proceeded on schedule.

The ETS-1 Interface System Design was revised and redrawn for an installation cost estimate and schedule. The ETS-1 Interface Systems status was periodically transmitted to SNPO-C.

A complete analysis, ETS-1 Cooldown System Pressure Drop Analysis was submitted to SNPO-C to indicate an ETS-1 adequacy in respect to XE cooldown requirements

Data were prepared on cool-down system valve properties and transmittal made available for the Engine group incorporation in the Cool-down Simulation Computer Program.

3.2.5 ETS ACTIVATION PLAN

Data for updating the SNPO-C ETS-1 Management Network and Activation Network Summaries was monitored. Field surveillance and guidance was provided for the activation plans and procedures for the ETS-1 Complex.

In conjunction with the above, a study was completed to more adequately define the effort involved in the conduct of each NTO activity, including NES integrated testing, through XE-Engine testing. This effort included facility experimental plans in sufficient detail to permit an analysis of time span requirements. The facility experimental plans include definitions of scope, summary and objective, pre-test, test, operator and facility systems requirements, post-test/securing operations, data analysis and corrective action, general instructions, and control room procedures.

Charts were prepared to cover gas and fluid utilization for specific sequences of operation.

Count schedule bar charts were also updated in support of the Gas and Liquid Utilization Summary Schedules.

3.2.6 ENGINEERING SUPPORT

Efforts were continued to provide technical assistance and engineering support on the ETC eutectic seal gate test fixture and the ETC seal gate design verification test program.

Studies were continued for including low source radiation specimen holders in the Engine Test Compartment to provide a known sample for calibrating the facility neutronics system located in the side shields.

Engineering Support and Documentation preparation was provided for the development of the Engine Test Compartment activation test plan for a test program to be conducted at ETS-1. This preliminary ETC Test Plan is in process and is approximately 90% complete. A preliminary ETC/NES Activation Schedule was completed.

As a result of raising the ETS-1 Facility thrust structure, an analysis and recommendation was transmitted on 7 April 1965 to SNPO-C, regarding modifications required at ETS-1 for the XE Shielding Engine Test Compartment Interface.

Drawings and a preliminary cost estimate were prepared for modifying the Engine Test Compartment to permit a 12-inch diameter penetration through the Intermediate Shield to satisfy the cool-down requirements existing at that time. The need for this line was later eliminated.

A preliminary design of the ETC Gas Sampling Pump and Analyzer System is in progress. Calculations are being made for the sizing of the GH_2 Cooldown Line and calculations were completed on the ETS-1 Engine Test Compartment Radiation Shield.

3.3 ETS-1 INSTRUMENTATION & CONTROL (I & C) SYSTEM

EG&G ETS-1 Liquid Level Capacitance Probe Operational requirements were re-evaluated, and the results were transmitted to SNPO-C and EG&G for incorporation in the applicable documents.

The installation of the Miscellaneous Craft Work Packages was monitored and the necessary field change coordinated to ensure compatibility with facility and I&C requirements. Recommendations based upon the EG&G I&C System installation interface were made to SNPO-C relative to schedule slips. Approximately 15 Miscellaneous Craft Work Meetings with EG&G, CATCO, and SNPO-N were held to resolve various installation problems, including scheduling.

The TC&P installations, which were completed during this quarter, were monitored, and trouble sheets to effect necessary field changes were prepared. SNPO was advised regarding contractor's installation delays. Engineering evaluations were performed on the cable test results received from the TC&P contractor. Evaluation of questionable thermocouple cable test results continued.

The following activities were performed during the quarter:

Establishment with EG&G of the recording locations of the parameters required for the I&C System checkout;

Determining those signal conditioning cards which are utilized with the facility parameters;

Engineering calculations to determine precision resistor values for signal conditioner calibration, range, and completion networks;

Engineering surveillance of the I&C System installation;

Reviews of various EG&G documents, including updated system design drawings, preliminary system checkout procedures, operation and maintenance manuals;

Preparation of a preliminary Data System performance procedure;

and coordination of the I&C System Interfaces with other construction packages such as shields and interface systems.

3.5 E-MAD FACILITY COMPLEX

Designs and layouts for soft roof walkways, roof safety rail, E-MAD Facility fencing and perimeter lighting, emergency generator, security and bonded storage area, tool crib, personnel doors, emergency exits, and outside lighting were prepared and submitted to SNPO-N for review and approval. A specification for installation and checkout of the E-MAD closed circuit TV system was prepared and submitted to SNPO-N for their use in placing a TV installation contract.

Photographs and detailed measurements of the Post-mortem Cell dimensions which interface with Post-Operative Cell Material Transfer System (POCMTS) were determined. Re-evaluation and justification of the basic operational and engineering requirements for POCMTS were also provided.

Engineering review and coordination was provided to SNPO for the Master Slave Manipulator roller tube assembly design proposed by Central Research Laboratories, Inc., and to rectify the interfaces between the facility and the cell service area rectilinear manipulator.

Designs of the E-MAD add-on equipment, i.e., metallograph, microhardness tester, gross and incremental gamma scanners, etc. were reviewed, and specific locations were defined for the equipment within the E-MAD area.

A list was prepared of all post-operative equipment which will either be transferred from R-MAD or be newly procured for E-MAD. A preliminary cell assignment was then set forth for each piece of equipment, giving consideration to operational and building constraints, and product flow.

Comments on the Wall Mounted Handling System Acceptance Test Plan were submitted to SNPO-C and Vitro Engineering Company; the Overhead Positioning System Acceptance Test Plan review and acceptance is expected to be complete by 1 July 1965.

A study was prepared and presented to SNPO-C and Vitro Engineering Company representatives detailing the funding and minimal facility equipment recommended for an operational core disassembly and examination cell to support the NERVA Engine Program.

3.6 TEST CELL "A"

During this report period NRX-A3 testing activities utilized the Test Cell "A" Facility until 2 June 1965. After the removal of NRX-A3 to the MAD Building, the facility was decontaminated so that normal modification and preventative maintenance activities could resume.

Prior to the time of removal of NRX-A3 to the MAD Building, modification designs were finalized and approved, and specific work orders were written so that materials and long-lead items could be procured. Detailed work schedules were prepared and work begun to meet a tentative Facility Checkout Experimental Plan on 19 August 1965.

In addition to the above, fabrication of cryogenic piping for EST was started. Material for EST auxiliary gas system and the EST reactor flare boom was ordered. Civil work was started for additional LH_2 conversion pump in dewar area. Local control box relocation for nozzle cover boom was completed.

3.8 NRDS RADIOACTIVE MATERIALS COMPLEX

Monitoring of Radioactive Materials Storage Facility (RMSF) construction was performed and coordination and assistance was provided as required. Construction was Completed on concrete bunkers One and Two. Three miles of railroad track and three miles of messenger system pole lines were completed, as was approximately two miles of 1500-watt Iodine Quartz perimeter lighting. The installation of four miles of security and perimeter fencing is expected to be complete by 1 July 1965.

SECTION III (CONTINUED)

TECHNICAL DISCUSSION
TASK 4

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4.0 PROGRAM MANAGEMENT

4.1 PROGRAM PLANNING AND CONTROL

The work during the period consisted of routine bi-weekly updating, reporting and evaluation of the active PERT Networks. These included the Aerojet portion of the NRX-A4/EST, NRX-A5, NRX-A6, CFDTS, XECF/XE-1, ETS-1 and E-MAD networks.

During the months of April and May considerable activity was devoted toward rearranging program plans and providing corresponding adjusted versions of the PERT and Milestone reports. Summary networks for each of the test articles and facilities were developed, as were the corresponding End Item Milestone Charts. These documents were included together with data describing the agreed upon Subtask Milestones for CY '65 in the Second Quarterly Milestone Report Supplement. This document also supported and helped define the schedular aspects associated with the Agency Budgets for CY '66 and '67, submitted during the quarter.

An activity of simultaneously developing Milestone and PERT procedures, thus permitting a close interrelationship, was sufficiently completed to be used in preparing the Second Quarterly Milestone Report Supplement to the Quarterly Informal Progress Lietter. A description of the procedures was included in the Milestone Report.

.2 FISCAL CONTROL

During the reporting period, cost reports were prepared and submitted in accordance with the requirements of the work statement. In addition, the annual budget study for three years of the development program was prepared.

Liaison between SNPO-C and REON Fiscal Control continued on a revised cost reporting format.

4.3 TECHNICAL REPORTS

During the third Quarter of Contract Year 1965, the following reports were published, all titles being unclassified:

EXTERNAL DISTRIBUTION

Report	Title	Publication Date	Classification
2275 (Rev.)	Materials Properties Data Book	4-2	Uncl.
2277 (Rev.)	Radiation Effects Data Book	4-2	C/RD
2277 (Rev.)	Radiation Effects Data Book	5-29	C/RD
2320 (Rev.)	Instrumentation Data Book	4-30	C/RD
2578 (Rev.)	Program Requirements Document	4-22	Uncl.
RN-S-0134	Preliminary Report on Nuclear Radiation Heating of Components in the NERVA Engine	4-26	C/RD
RN-S-0158	Pressure Vessel - Nozzle Seal Assy. Confirmation Test 1070N Evaluation	6-11	CONF.
RN-S-0205	Upper Thrust Structure S/N 0000001 Static Structural Test Evaluation	5-5	Uncl.
RN-S-0216	Lower Thrust Structure S/N 0000001 Static Structural Test Evaluation	4-28	Uncl.
RN-0560-10-35	Informal Progress Letter No. 35 (Technical Section)	5-15	Uncl.
RN-DR-0059	Management Controls for NRX/EST Testing	4-21	Uncl.
RN-TM-0145	Basic Loads & Structural Design Criteria for the NRX/EST Engine	6-2	Uncl.
RN-TM-0171	Evaluation of the NRX-A2 Pressure Vessel & Propellant Inlet Line	5-5	Uncl.
RN-TM-0187	Simulated Guide Tube - Pressure Vessel Closure Joint Test Evaluation	5-3	Uncl.
RN-TM-0207	Failure Analysis Report - S/N 2H Nozzle	6-1	Uncl.
RN-TM-0209	Evaluation Reports NRX-A Pressure Vessel Closure Seal Cryogenic Test Series II	6-25	Uncl.
RN-S-0215	NRX-A2 Nozzle - Chamber, Tungsten - Rhenium Thermocouples	6-14	CONF.
RN-TM-0217	Structural Analysis & Non-Nuclear Components for NRX/EST Engine System (Part I)	6-11	Uncl.

LIMITED DISTRIBUTION*

Report	Title	Publication Date	Classification
RN-S-0109 (Rev.)	Evaluation Testing of Bendix NT-C2 Series TPCV Actuators	4-2	Uncl.
RN-S-0210	Final Test Report for Phase I of the Countermeasure Radiation Effects Program	5-11	C/RD
RN-S-0212	Systems Analysis Procedures & Techniques	4-14	Uncl.
RN-S-0213 2 Vols.	CFDTS Pre-Test Predictions	4-28	Uncl.
RN-S-0217	Final Report for Phase I-B of the Countermeasures Radiation Effects Program		C/RD
RN-S-0218	Preliminary Test Report for Phase I-D (Kiwi-TNT) of the Countermeasures Radiation Effects Program	5-11	C/RD
RN-0560-10-35	Informal Progress Letter No. 35 (R & QA Supplement)	5-15	Uncl.
RN-0560-10-35	Informal Progress Letter No. 35 Milestone Supplement	6-5	CONF.
RN-0560-10-35	Informal Progress Letter No. 35 Milestone Supplement Revision	6-22	CONF.
RN-DR-0058	Presentation to SNPO - Cost Review Contract Years 1965-1966-1967	4-14	Uncl.
RN-DR-0058 (Reprint)	Presentation to SNPO - Cost Review Contract Years 1965-1966-1967	4-20	Uncl.
RN-FR-0015	Monthly Fiscal Report (March 1965)	4-22	Uncl.
RN-FR-0016	Monthly Fiscal Report (April 1965)	5-21	Uncl.
RN-FR-0017	Monthly Fiscal Report (May 1965)	6-23	Uncl.
--	Preliminary Draft - NRX/EST Safety Evaluation Report	5-1	C/RD

* Limited distribution reports include those published as internal reports

The summary motion picture for CY 1964 was completed and the First Answer Print was forwarded to SNPO-C. Work continued on the photography and script preparation for the CY 1965 report film.

At the end of this reporting period, work was in process for the preparation and submission of RN-A-0004, entitled Budget Estimate 1967 NERVA Development Program.

NERVA weekly Highlights TWX's numbers 0090 - 0101 were issued for weeks of 6 April through 24 June, all unclassified.

4.4 CENTRAL DATA SYSTEM

A detailed Drawing Data Retrieval System was established which generates a report for drawing product description, number of drawings, average ratio to top assembly drawings.

A system was established to provide test data from NTO to REON Central Data Control. Test data are sorted in alpha numeric order which makes them accessible for engineering review. Microfilm is placed in cartridges in the same sequence, which enables the engineers to view the data on the Recordak Lodestor Reader-Printer. and to generate hard copies as required.

Geometrical cross-section analysis of NRX test stand configurations was provided, nozzle volume was calculated, and general support was supplied for irradiation analysis.

Test data was supplied for NRX-A1, NRX-A2, NRX-A3 and Kiwi in the following forms:

- Oscillograph, CDC, and Sanborn records
- Digital printouts
- Cal-Comp plots
- Test data reports
- SC-4020 plots
- Magnetic tapes
- 35mm aperture cards
- 16mm cartridges

16mm microfilming continues on NRX-A1, NRX-A2 and Kiwi Test Data, with an Indexing System for locating specific data which provides viewing or reproducing capabilities.

Analysis and programming was provided for the following documents:

- Project Status Report
- Program Requirements Document
- NRX/EST, A4, A5, XE-1 and CFDTS Measurements Requirement List

Support Equipment Provisioning Lists

Government Specifications and Standards Index

REON Parts Listing

Support Equipment Technical Description Handbook

35mm microfilm aperture cards of drawings on the NERVA Program were provided to SNPO-C and WANL on a regular basis.

16mm microfilm of indexed NERVA Specifications was provided to SNPO-C.

4.6 SPECIAL PROGRAM SERVICES - TECHNOLOGY UTILIZATION PROGRAM

Two changes in operating procedures occurred during this quarter. Submission of informal monthly progress reports was instituted for Subtask 4.6 to provide statistics on techniques, and procedures of gathering TU information. These reports have been submitted in May and June for the preceding months. The second change involved the Flash Sheet format, which was revised by SNPO to provide more detailed information, particularly concerning any possible patent action by the contractor or contractor recommendations to NASA. The innovation description was shifted to the Tech Brief format to avoid a later rewrite by NASA.

During this period, 37 items were reported to the TU office, with 7 items carried over from a previous period. Of these 11 were rejected as not constituting a true innovation, 15 were pending final action as of 30 June, and 18 were submitted to SNPO-C. In acquiring this data, 260 interviews were conducted with engineering and technical personnel, and 97 documents were reviewed.

Technology Utilization documents received from NASA during this period included 157 Tech Briefs and book on advanced bearing technology (SP-38). This latter document and 8 of the Tech Briefs are potentially useful to Aerojet and are in the hands of the engineering personnel involved.

SECTION III (CONTINUED)

TECHNICAL DISCUSSION
TASK 5

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5.2 AGC LRO CRYOGENICS LAB (TEST ZONE A)

The pump impeller spin test system, previously damaged during a test conducted in March, has been reconstructed. Reconstruction of the system was accomplished by the latter part of April.

Two 10,000-lb cryogenic dewars were received from Cryogenic Engineering Co. on 14 June. The dewars will be installed in the Cryogenics Laboratory for use in fatigue and impact testing of metallic specimens.

5.3 AGC LRO TEST ZONE H

An overall view of Testing Complex H-4, H-4A, H-4B, H-5 and H-6 showing all basic tankage and piping systems is shown in Figure 70. The supersonic diffuser cart and chamber section shown in the center foreground is designated as Test Stand H-4. Directly behind Test Stand H-4 within the superstructure and beneath the smallest spherical vessel is Test Stand H-4A with Test Stands H-5 and H-6, respectively, to the right of H-4A. The concrete apron adjacent to the left side of Test Stand H-4 is the site of Test Stand H-4B. Extending into the right foreground from the Testing Complex is the CFDTS ejector system. The LH_2 catch vessel (VH-10) and flare stack are partially hidden behind the right side of the complex.

The activation of Test Stand H-5 was accomplished on 15 April with the initiation of CFDTS-1 testing. A series of six wet start tests were conducted during which the feasibility of the "bootstrap" concept was demonstrated.

A handling fixture to facilitate the installation and removal of the TPA for the CFDTS was received on 20 April. Installation of the fixture on the CFDTS handling cart was accomplished on 22 April.

In Figure 71, the CFDTS handling cart is shown on the rails in front of the test position H-5. The cold-flow machine can be seen suspended within the superstructure in Test Stand H-5.

Checkout of the two-stage ejector systems for the nozzle and turbine which will be utilized during the next group of CFDTS tests to be initiated. Initial attempts at ejector performance tests were unsuccessful due to the inadequacy of the actuation system for the main flow control valve. The pneumatic actuator furnished with the valve permitted extreme oscillation in ejector GN_2 flow rates. Substitution of a hydraulic actuator in lieu of the pneumatic actuator resolved the difficulty through the improved response characteristics of the hydraulic actuator.

Subsequently, several preliminary flow tests of the ejectors were conducted with satisfactory results. However, final checkout of the systems will not be accomplished until just prior to the next group of CFDTS tests when the hardware effluence of GH_2 can be utilized. The uniting of the hardware effluent flows with the flow of "spoiler" gas within the ejector systems is a necessary condition for testing the adequacy of the ejector systems in maintaining a controlled backpressure condition.

The CFDTS ejectors and some of the associated piping systems are shown in Figure 72.

TPCV testing, with heated hydrogen as the drive media, was initiated on 28 April. With the commencement of TPCV testing on Test Stand H-4A, the activation of the primary NERVA non-nuclear test facility in Zone H is complete.

Duration of heated hydrogen drive TPA tests on Test Stand H-6 continue to be limited by problems involving the GH_2 high pressure receivers. Because of the possibility that hydrogen embrittlement of the receivers is occurring as a function of high pressure (5,000 psi), the existing system has been downgraded to 3,500 psi. In order to augment the GH_2 supply for Zone H, 3 high-pressure GH_2 receivers from the M-1 Program are planned for relocation from E Zone to H Zone.

The high pressure receivers in Test Zone "H" are shown in Figure 73. The concrete "sleepers" to the left of the existing receivers, are for installation of additional receivers to augment the GH_2 supply.

The "Velan" hot gas control valves that had failed at the stem guide, as had been previously reported, have been repaired and returned to Aerojet. The valve stem guides were made removable and "Haynes (Stellite) 25" was installed in lieu of the original "Stellite 24" as the stem guide material. The valves have been reinstalled in the hot gas system and are operating satisfactorily.

Figure 74 shows a "Velan" hot gas control valve and actuation system in operating position as the turbine drive valve.

An inspection of the hydrogen heat exchanger was conducted on 4 June. One of the supports for the radiant tube section had burned through and some deformation of the tube bundle was noted; in addition, deterioration of the exterior of one of the tubes was apparent.

Investigation into the cause of the heater problems indicated that the tube supports were too rigid. On 28 June, the heater fabricator (Twyman Engineering Co.) initiated a "fix" for the tube supports. The original rigid parallel supports are being replaced with steel rods woven through the tubes in the tube bundles. The support offered by the "woven" support is more flexible than the original clamp type support and is more adequate for adapting to the stresses imposed by the expansion of the tubes when the heater is in operation.

The hydrogen heat exchanger facility is shown in Figure 75, as seen from high in the 5-story superstructure of the NERVA testing complex.

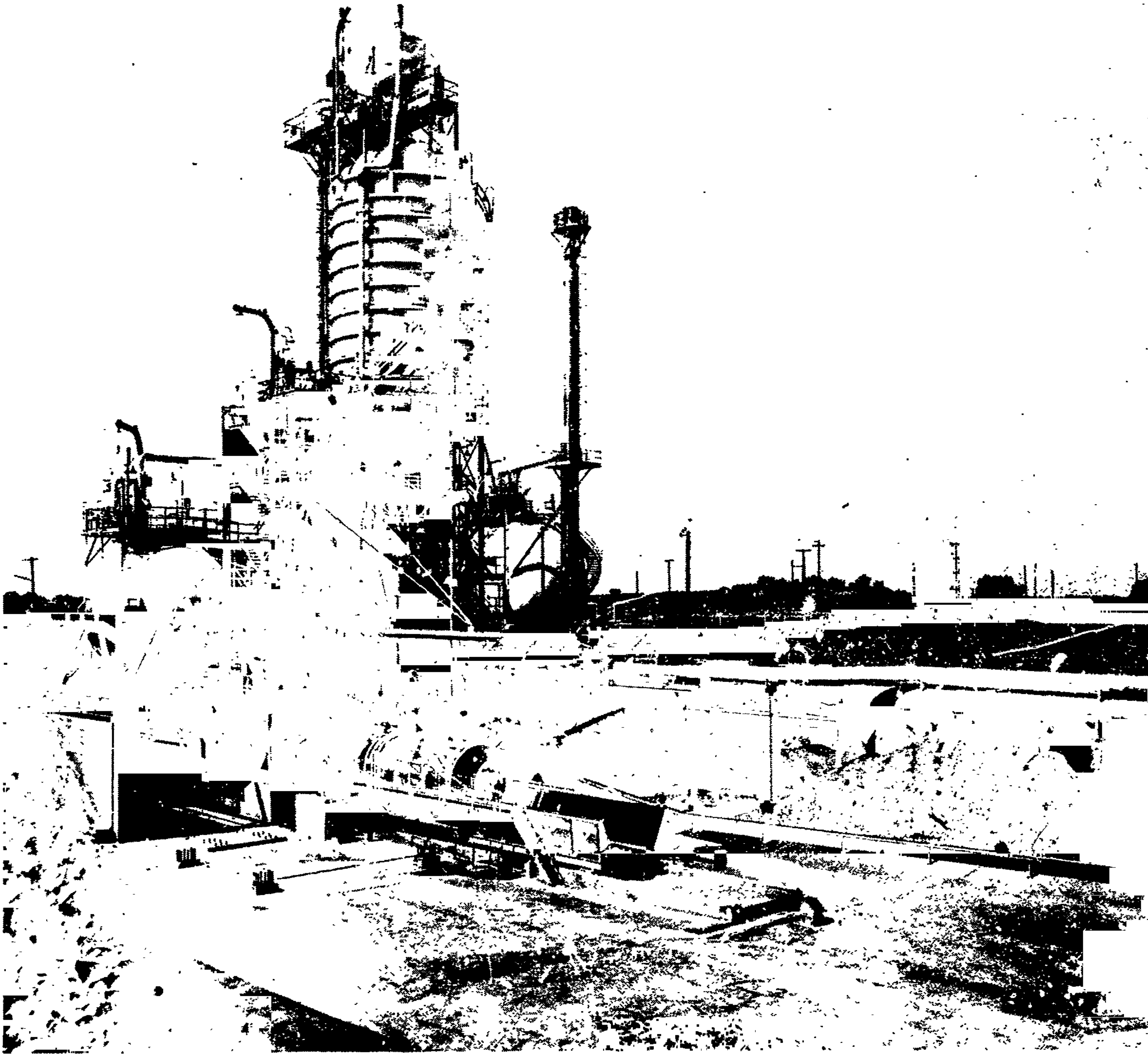

Figure 70

NERVA Testing Facilities

H Testing Complex

Sacramento Plant, Aerojet

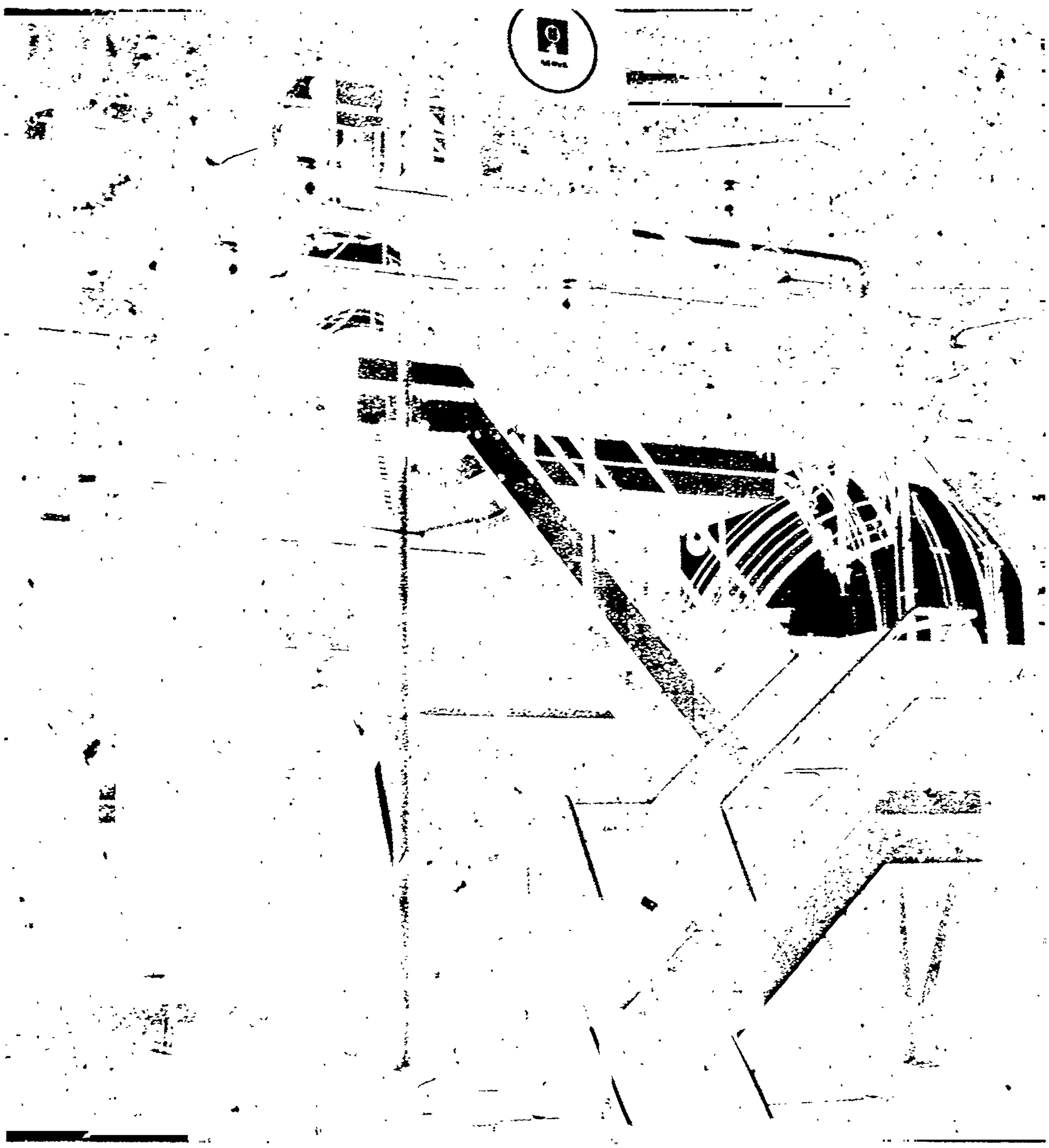

Figure 71

CFDTS Handling Cart
in Front of Test Position H-5
Sacramento

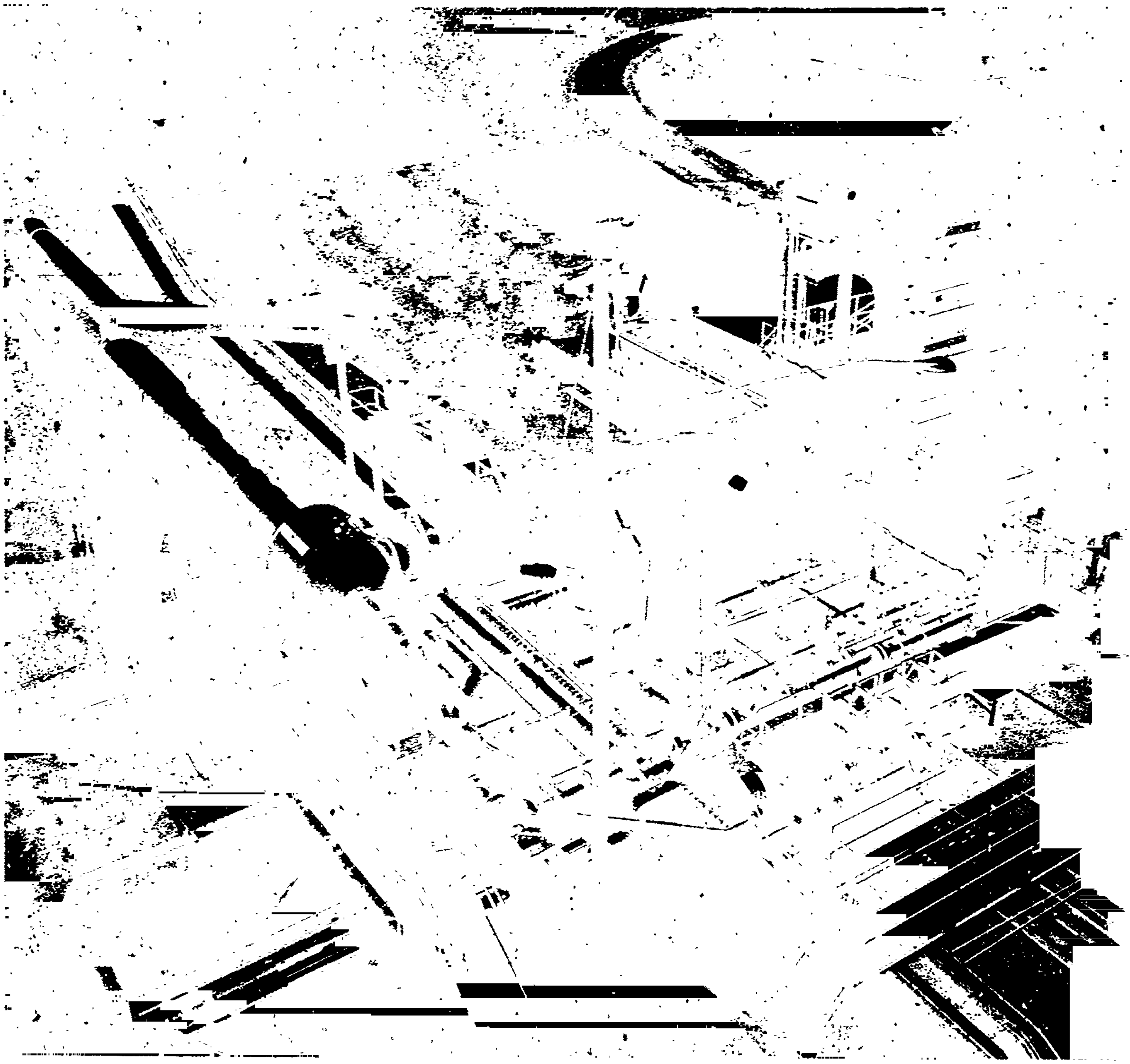

Figure 72

Two-Stage Ejector Systems
and Associated Piping
for CFDTS Nozzle and Turbine Testing
Test Stand H, Sacramento

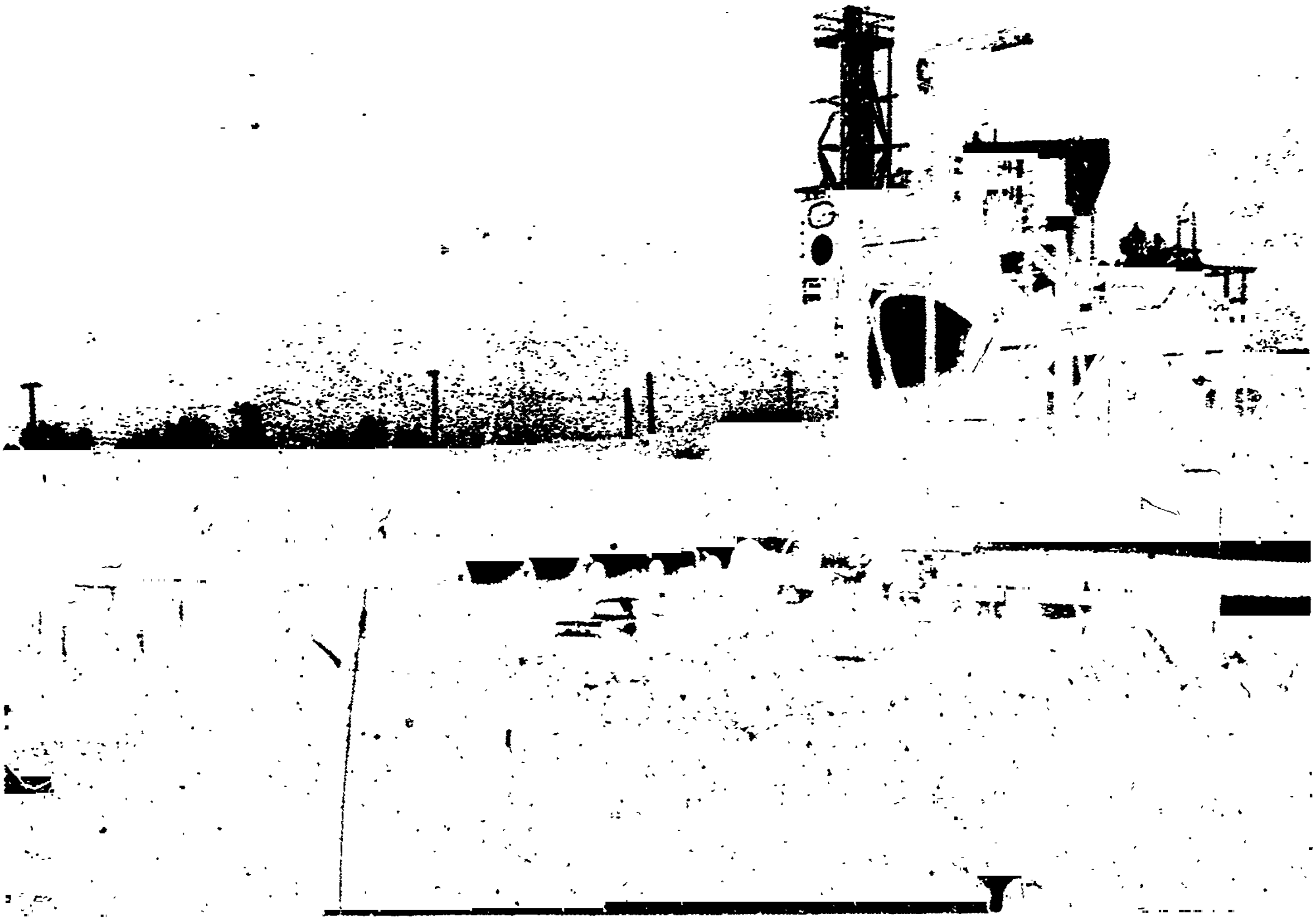

Figure 73

GH_2 High-Pressure Receivers
H Test Area, Sacramento

Figure 74

Velan Hot Gas Control Valve
and Actuation System
in Operating Position as Turbine Drive Valve
Test Stand H, Sacramento

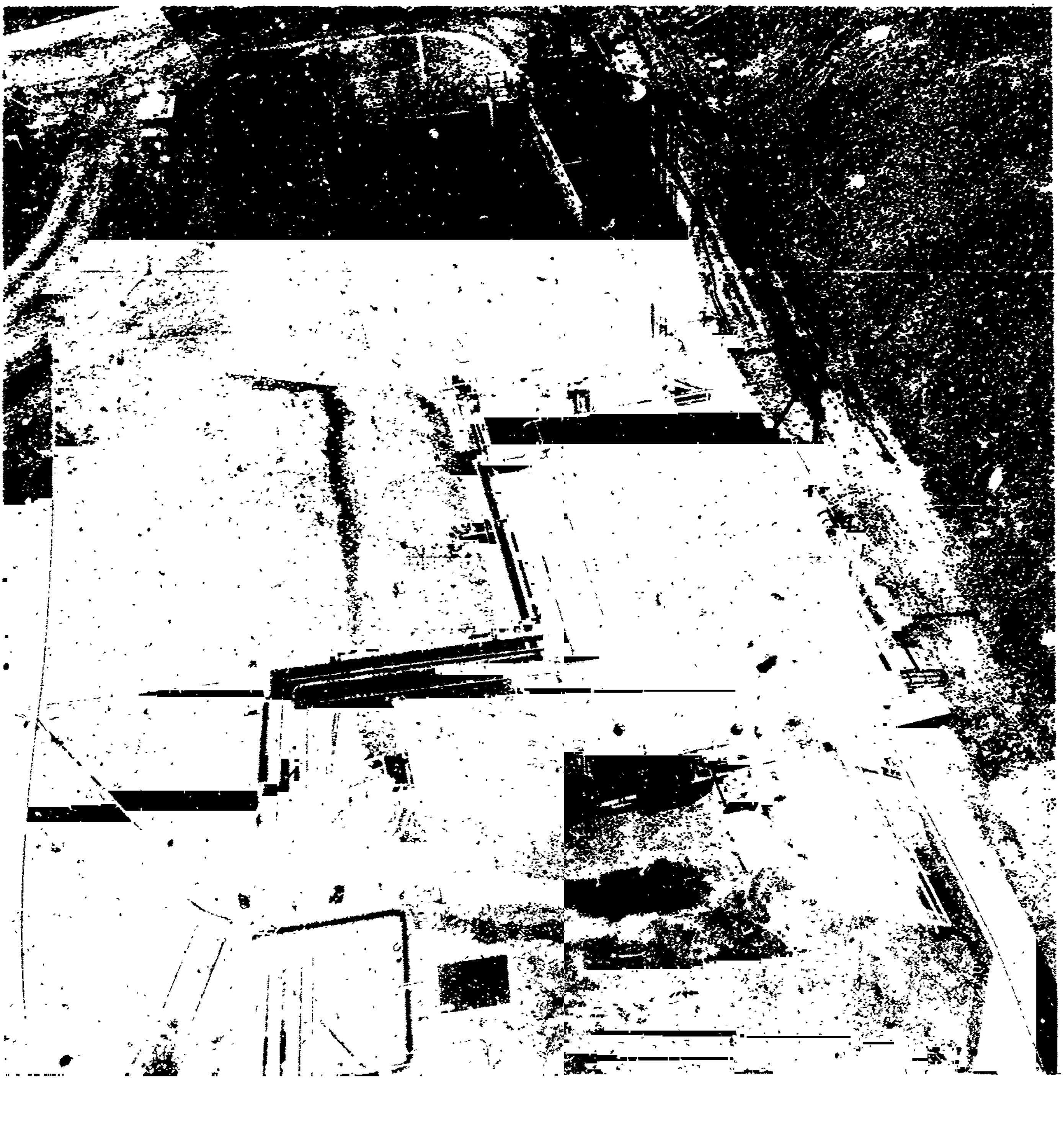

Figure 75

Hydrogen Heat-Exchanger Facility

Test Area H, Sacramento

5.8 AGC LRO/SRO MISCELLANEOUS LABORATORIES

Specification 9270-5383 for a cryostat for calibrating high sensitivity RTT's has been finalized. The design concept includes a liquid helium cooled cryostat with a large copper test block inside. The RTT's to be tested will be inserted in the copper test block and be compared to a platinum resistance standard to be also inserted in the block. The standard is to be NBS (Washington) calibrated. The cryostat will calibrate up to 12 RTT's during a run and will operate over the -425° to -297° range.

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SECTION III (CONTINUED)

TECHNICAL DISCUSSION
TASK 6

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6.2 GOVERNMENT PROPERTY

A hydrogen leak alarm system for the test bays of the Cryogenics Laboratory has been designed and procurement of components initiated. Completion of the system is anticipated for August 1965.

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SECTION III (CONTINUED)

TECHNICAL DISCUSSION
TASK 7

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7.0 NRDS GENERAL SUPPORT

Detailed test site schedules were prepared for NRX-A3 and NRX-A4/EST reactor testing, assembly, disassembly, post-operative inspection, hardware delivery dates, required document preparation dates, and Test Cell "A" activities.

The procurement of propellants and pressurants was scheduled, commensurate with requirements dictated by test activities.

Revision 1 to the 3rd Annual Edition of the Program Requirements Document (Report 2578) was prepared.

7.1 TEST CELL "A" OPERATIONS

A. TEST CELL "A"

On-site test engineering necessary to ensure compliance with the test objectives and requirements detailed in NRX-A3 specification was provided.

Test Cell "A: facility operations for NRX testing, were continued; this included:

Assignment of personnel to direct and conduct the technical activities of TC"A" operations.

Establishment of requirements for Machinery Maintenance and Spares.

Approval of modifications to Test Cell "A , including those necessary to support Engine System Test, so they are properly initiated and/or implemented.

Daily maintenance of the Test Cell "A" systems was provided by the test operation team, and direction was provided to the support services contractors (Pan AM and EG&G) in the maintenance of the facility and subsystems of which they have established responsibility.

B. CONTROL SYSTEMS

Limiter circuits were installed, checked out, and used during NRX-A3.

A reactivity computer was designed, built, and checked out, and used during NRX-A2-EP-II to measure drum integral worth.

The ram positioning stop drive motors were replaced and checked during NRX-A3.

During NRX-A3 after EP-IV and prior to EP-V, filters were installed on the hydraulic systems inputs into the flow shut-down and scram chain.

Station 8 and Station 20 averaging chassis were redesigned and rebuilt to correct problems during the A3 series.

The tie-rod exit temperature averaging chassis was modified to correct a discrepancy which prevented the automatic averaging and rejection of these temperatures.

A new flow shut-down flow program was incorporated on PCV-41 gas control valve.

The design objectives and criteria to be used in EST control systems were established.

C. NUCLEAR ANALYSIS AND ENGINEERING SUPPORT

A second rabbit gun, located radially from the reactor, was designed and installed at Test Cell "A". This rabbit gun, in conjunction with the axial rabbit gun, was installed in order to investigate the relationship between axial and radial leakage from low to high reactor power. Checkout of both rabbit guns was completed in preparation for the NRX-A3 test series.

The design package required for installation of the side-by-side accelerometer test was completed and issued. Engineering follow and coordination was provided during installation and checkout of this system. The system functioned properly throughout the NRX-A3 test series and was removed subsequently to test.

A test program was carried out to verify the cause of abnormal oxygen analyzer behavior during the NRX-A2 test series, in which the analyzer pegged negatively at reactor power levels greater than 15 Mw. A temporary gamma shield was installed prior to NRX-A3 testing which will be replaced with a permanent shield to overcome this problem.

All preparatory work for the NRX-A3 dosimetry program was completed by NTO personnel. Off-site shipments of irradiated dosimeter materials were completed and analysis of dosimetry data at NRDS is in progress. In conjunction with the dosimetry program, DOSCO, a dosimetry program was expanded to increase its flexibility for data reduction.

Detail design was completed to permit installation in Test Cell "A" of a LH_2 vaporizer to provide GH_2 to tank farm using dewar-stored LH_2, and replacing a presently installed unit of marginal capability. This design package included the required structural, electrical, and piping details.

In support of the NRX-A3 test series, the power calibration data, rabbit gun data, and test data were analyzed.

An analysis of an LH_2 pipe rupture accident within the Flow Control Room (FCR) was completed to determine the relief area required to preclude structural damage to the FCR structure. As a result of this study, detail designs were prepared to significantly increase the FCR relief area and thus limit the internal pressure buildup.

Engineering coordination was provided for the installation of the new gaseous nitrogen bank at TCA.

TCA radiation survey data, obtained during the NRX-A3 test series, has been collected and is currently being analyzed to define shielding requirements and material activation problems.

D. DATA ACQUISITION AND INSTRUMENTATION

Channel engineering and data processing were accomplished for the six experimental plans of NRX-A3.

A data evaluation team was formed, consisting of AGC, WANL, EG&G, and NTO, to check channel engineering documents against established requirements prior to the end-to-end instrumentation check and to evaluate EP-I data to uncover data system or setup discrepancies prior to each EP.

The following new work orders were issued for EG&G direction:

> Installation, design, and checkout of 8 low level multiplexers and 100 data amplifiers. Partial delivery of components to NTO has been made and acceptance tests are in process.
>
> Design and installation of a calibrator for the narrow band system.
>
> Procurement and installation of a tuneable-filter discriminator for checking out the wideband system.

The following special work items have been completed:

> Replacement of damaged instrumentation in the Dewar "C" area.
>
> Drift problems on 6 CEC differential pressure transducers have been uncovered. Solution of problems concerning the demodulator system and low excitation on strain gage pressure transducers.
>
> An investigation was made on tie rod temperatures following NRX-A3 EP-IV to determine maximum temperatures reached,

and to establish whether continuation of testing was possible. This analysis confirmed predicted values, and the "go-ahead" was given for EP-V and VI.

A study was completed on several accelerometers to determine their maximum output values beyond the full scale setup range.

Data system accuracy is being checked by a new Data System Evaluation Procedure.

E. DOCUMENTATION AND REPORTING

Final drafts of all NRX-A3 Post-Test Procedures were issued, including:

NRX-A3-P18, Test Car - Test Cell Disconnect Procedure.

NRX-A3-P19, Test Area Radiation Survey.

NRX-A3-P20, Disassembly Procedure.

NRX-A3-P23, Test Assembly Post-Operative Examination Procedure

Final drafts of these NRX/EST Procedures were issued:

NRX/EST-P1, Reactor/Vessel Receiving Inspection

NRX/EST-P2, Non-Nuclear Hardware Receiving Inspection

NRX/EST-P3, Engine System Assembly (Mechanical)

NRX/EST-P4, Engine System Assembly (Electrical)

Review drafts of these NRX/EST procedures wereissued:

NRX/EST-P5, Test Article Mechanical Assembly

NRX/EST-P6, Actuator Installation and Checkout

NRX/EST-P7, Test Assembly Electrical Hookup and Checkout

NRX/EST-P8, Test Car/Test Cell Mate-up

Reports of the NRX-A3 Test Series were issued, including:

NTO-R-0030, Pre-Test Report, NRX-A3

NTO-R-0025, Three-Day Report, EP-I

NTO-R-0026, Three-Day Report, EP-II

NTO-R-0027, Three-Day Report, EP-III

NTO-R-0028, Three-Day Report, EP-IV

NTO-R-0029, Three-Day Report, EP-III-A

NTO-R-0031, Three-Day Report, EP-V

NTO-R-0032, Three-Day Report, EP-VI

NTO-R-0035, EP-IV Anomalies Report, NRX-A3

F. TEST PLANNING

The NRX-A3 test series, encompassing seven Experimental Plans, was completed at NRDS on May 28, 1965. All major objectives of the test plan were accomplished. In addition, many of the secondary objectives were satisfied, yielding a considerable amount of knowledge concerning the reactor operating map and various parameter transfer functions. The NRX-A3, as mounted ready for test on Test Car T-7, is shown in Figure 76.

Of the seven Experimental Plans, two were full-power runs (in excess of 1100 Mw) and a third a restart to approximately 400 Mw. The reactor was operated in the power range for a total of 33 minutes, of which 16.1 minutes was at full power. The full-power run of NRX-A3 is shown in Figure 77.

The seven Experimental Plans and the specific objectives accomplished in each test are briefly discussed in the following paragraphs:

1. EP-I-NRX-A3, April 7, 1965
INITIAL CRITICALITY

During this EP, initial criticality was obtained and the differential worth of the control drums, from 180° to criticality (89°), was obtained through piece-by-piece removal of the central poison wires. Gaseous nitrogen (88 lb/sec) and hydrogen flow tests (24 lb/sec) were performed to confirm predicted pressure drop information. A liquid hydrogen test was then performed (to 22 lb/sec) to gain information on propellant reactivity worth and hydraulic performance of the reactor system.

2. EP-II-NRX-A3, April 14, 1965
POWER CALIBRATION AND DRUM WORTH TESTS

The major objectives of this test were:

Actuation of power calibration devices;

Determination of differential and integral worth measurements of one control drum from 0 to 180°;

Determination of the bank worth from delayed critical using the rod drop method.

(Text continued on page 288)

Figure 76

NRX-A3 Mounted for Test
on Test Car T-7

Figure 77

Full-power Run, NRX-A3

3. EP-III-NRX-A3, April 21, 1965

NEUTRONIC CALIBRATION, FLOW TEST, AND SCALED-DOWN POWER TESTS

The major objectives of this test were:

Performance of liquid hydrogen flow startup profiles to optimize the technique required for the Full-Power Run;
Setting of low- and high-power neturon-detector positions;
Actuation of low power dosimetry;
Performance of scaled down full power run as a systems check for the upcoming full power test.

4. EP-IV-NRX-A3, April 23, 1965

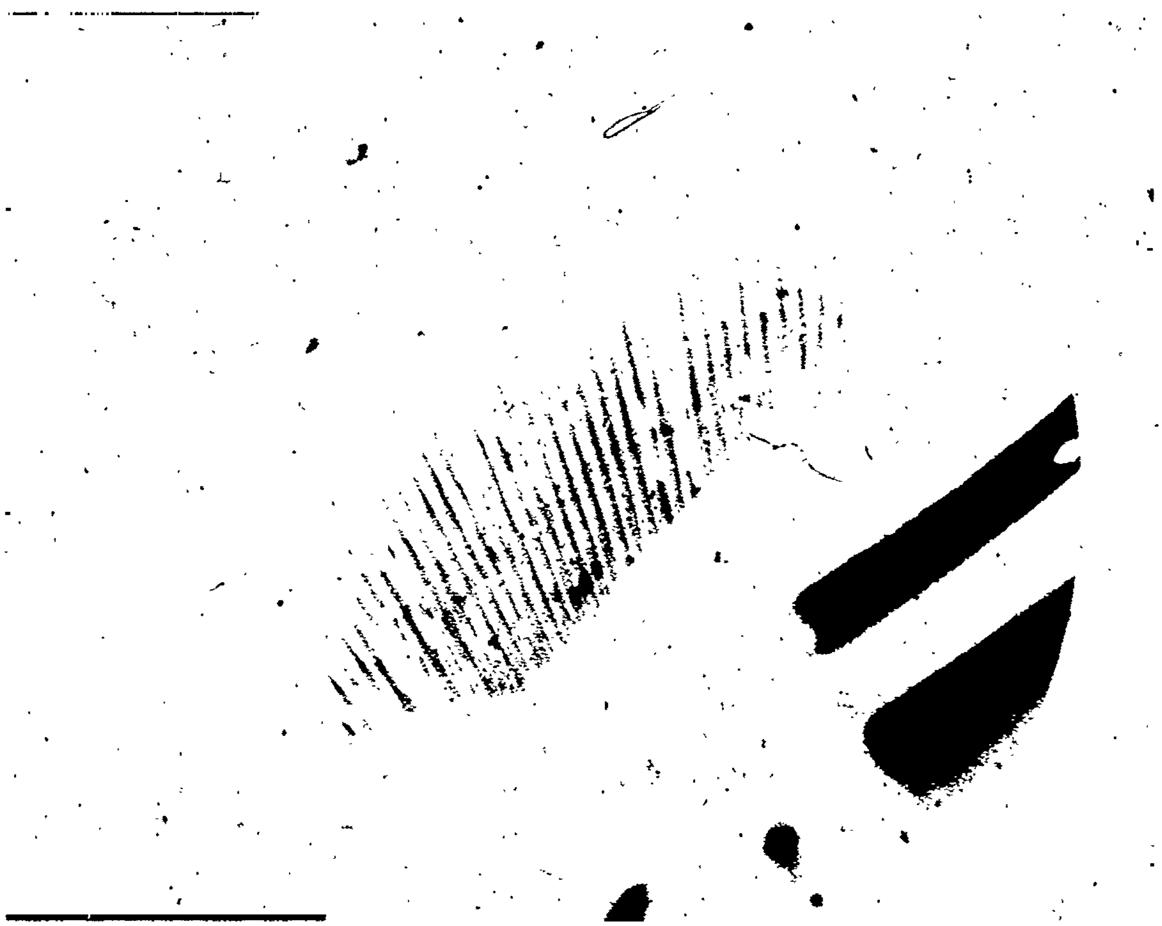
1ST FULL-POWER RUN

During this EP, particular requirements of the NRX-A3 Test Specification pertaining to full-power operations were partially satisfied. A spurious signal from the facility pump RPM transducer caused a flow shut-down 3.5 minutes after full power was attained. Immediately upon the flow shut-down, the reactor was scrammed and emergency GH_2 coolant was provided. The initial emergency coolant flow was sufficient to maintain acceptable reactor temperatures; however, after the liquid inventory in the propellant was exhausted, an upstream venturi choked, thus reducing the coolant flow rate. At this time reactor temperatures exceeded their limits until the Test Officer manually increased GH_2 flow. The effects of these high component temperatures required detail investigation, thereby precluding an immediate restart to full power.

5. EP-III-A-NRX-A3, May 13, 1965

FLOW TEST AND SCALED-DOWN POWER TEST

This test was a re-run of EP-III primarily to determine if the flow shut-down of EP-IV resulted in any serious damage to the test item. Coolant tube in the nozzle as viewed remotely on TV (see Figure 78) showed apparent failure (an illusion which was removed by swabbing with paint). Based upon results of the tests as compared with previous EP data, it was concluded that there was no detectable change in the continuity of the flow passages on the nozzle and reactor. In addition, no evidence was found to indicate any structural defects in the reactor or nozzle.



Dark areas on corrugations
showed possible tube rupture

Figure 78

Divergent Section of Nozzle
Remote View during EP-IV

6. EP-V-NRX-A3, May 20, 1965
RESTART TO FULL POWER

The successful conclusion of this run satisfied those sections in the Test Specification pertaining to operation at full power. The reactor was operated in the power range for 16 minutes, of which 13.1 minutes were at full power.

During the full-power hold there was evidence of a slight reactivity loss, at constant rate, totaling approximately 50¢. This was well within the predicted reactivity losses. There were no operational difficulties encountered, and all components functioned in accordance with design predictions.

7. EP-VI-NRX-A3, May 28, 1965
ALTERNATE STARTUP TO FULL POWER

The primary objective of this EP was to explore the reactor operating map in the medium power region. In accomplishing this objective, many other secondary objectives were met, which are of prime importance in development of new control techniques. These experiments are listed below:

a. Startup from low power to medium power with locked drums and flow rate control from zero flow (1Mw) to 10 lb/sec (35 Mw).

b. Locked drum - flow programmed test from 10 lb/sec (35 Mw) to 46 lb/sec (310 Mw).

c. Control-system frequency response measurements at various points on the operating map, which provided useful information for the design of EST control systems.

On June 2, 1965, the NRX-A3 test assembly was successfully disconnected from Test Cell "A" and returned to the R-MAD Building for disassembly

Twenty-four hour and 3-Day Reports were issued for each EP. The 36-Day Report is scheduled for release July 6, 1965.

7.3 R-MAD AND POST-MORTEM OPERATIONS

A. NRX TEST CAR ENGINEERING

Test Car T-7 (NRX-A3) was disconnected from the test cell, moved out of the test cell compound, and then remotely remated to the test cell. Recoupling of the electrical coupler and subsequent electrical checks showed all systems operating satisfactorily. Car T-7 is presently located in the hot dump where it is being allowed to decay. See Figure 79.

Test Car T-2 has been assembled from a basic frame to the point where it is presently ready to accept the NRX/EST pump package. All Phase I wiring is complete and electrical checkouts are being made. The connector plug, counter weights, privy structure, privy roof, hydraulic and pneumatic piping, 2" front deck plate, 2" front privy wall, and outriggers, have all been installed on the car.

Final design of the modifications to the Titan I decontamination unit which will be used to clean test-car piping has been signed off. The modification work has been started and all required hardware has been purchased, or is in the process of being purchased.

Design of a NRX/EST facility flow test car has been initiated and is about 50% complete. Hardware for this test car piping is in the process of being purchased.

Test Car T-6 electrical cables became water soaked during the time the car was out in the hot dump decaying to an acceptable level. These lines have been pumped dry so that the car is now ready for use.

B. ASSEMBLY OPERATIONS

1. <u>NRX-A3</u>

The test article was assembled in accordance with appropriate procedures. Pad support was supplied to assist in test article preparation for the successful experimental plans.

Remote recovery, including a remote re-mate of the test article, was completed on June 2, at which time disassembly and post-operative examination was started.

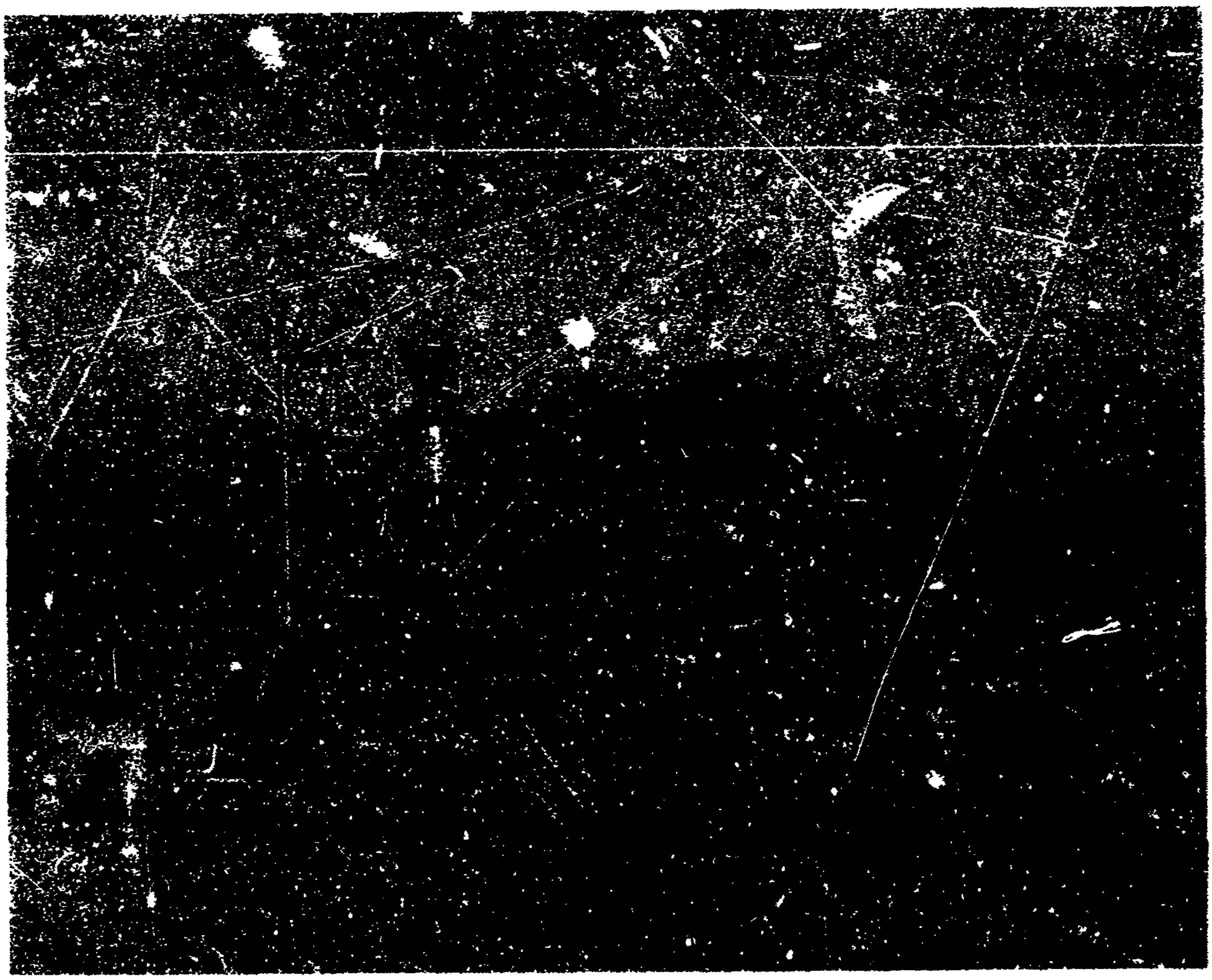


Figure 79

NRX-A3 on Test Car T-7
In Hot Dump after Test

2. NRX/EST

The modified car frame weldment arrived at site on April 8. Numerous defects were noted; those affecting the structural integrity were repaired. The connector plug weldment was received and re-inspected. Numerous defects were noted and repaired.

The build-up of the EST test car is about one month behind schedule, due to hardware and administrative problems. However, test car build-up is about 75% complete and is not expected to be a constraint on test assembly preparation.

C. DISASSEMBLY OPERATIONS

Set-up of the disassembly areas and hot cells was completed and operationally checked out prior to receipt of the test article for disassembly on June 2, 1965.

LASL's photo system for element photography was completed and operational at the time the test article was recovered.

Disassembly was started on June 2, and is completed; post-operative examination is being done as planned.

During disassembly operations, which were conducted on a two-shift basis, there were very few breakdowns or tooling discrepancies. Those that did occur are the subject of a separate report.

In addition the following was accomplished:

Handling trays were built for transfer of material to Post-Operative Examination from Disassembly

A3-GSE modifications were coordinated.

A Lennox periscope was installed and checked, and subsequently removed. The Kollmorgen periscope in Upper Bay was installed and checked out.

Tooling in Upper and Lower Disassembly Bays was installed and checked out.

Design layouts for A-5 tooling and equipment were reviewed.

Radioactive shipments to WANL, Large were coordinated.

Disassembly of reactor was started on June 3, 1965, with estimated completion on July 1, 1965.

D. POST-OPERATIVE EXAMINATION

1. In the Hot Cell operations and control, a completely new Hot-Cell Post-Operational Examination control system, was planned and executed, included the following:

Production control card system adapted to increase the efficiency of parts flow through hot cell.

Time study of operations applied to increase efficiency of individual hot cell operations and overall cell usage.

2. NRX-A3 P-23 Post-Operative Examination procedures were completed.

3. Equipment

Disassembly and Post-Operational equipment was designed,purchased, and installed to facilitate operations.

4. Element replication system

After the basic process feasibility was established by WANL, Pittsburgh, the following items were completed:

Design and procurement of special mold jigs and fixtures.
Specifying, locating, and procurement of required Silastic rubber processing equipment.
Determination of radiation damage effects on Silastic Room Temperature Vulcanizing Process.
Check-out and installation of equipment in hot cell.

E. RADIOCHEMISTRY LABORATORY

Four different categories of work were performed by the Radiochemistry section:

Seven types of computer programs were prepared and put into use. These cover the preliminary data reduction and final data computation required in connection with the whole body ionization measurements and axial gamma scan efforts on NRX-A3. Programs are in use for preparing cask insert maps and making listings of decay corrections for a number of fission products of interest.

Calibration wires from the NRX-A3 EP-II run were analyzed for neutronics calibration purposes. In addition, rabbits containing depleted uranium and nickel discs were irradiated during NRX-A3 EP-II, EP-III, EP-IV, EP-IIIA, EP-V, and EP-VI. The total fissions generated on each of those runs were calculated from the Mo-99 and Co-58 produced in the uranium and nickel respectively.

A number of samples were analyzed to determine their neutron activation products in connection with the various NRX-A3 power runs. These included water, oil, glass bottles, concrete, dirt, and rocks exposed on or in the vicinity of the Test Cell "A" pad, plus fall-out filter paper samples collected by the LASL H-8 group.

Gross ionization measurements were started on all NRX-A3 fueled elements. Axial gamma scanning of some 20 preselected elements was also begun. Data from these two examinations will be used to determine relative radial and axial fission distributions in the NRX-A3 core.

F. PHOTOGRAPHIC LABORATORY

A standarddistribution of photographs has been established for all photographs and motion picture footage on the NRX-A3 for off-site purposes. To date, 2800 photographs have been distributed plus 1500 feet of film in 16mm color.

NTO Photographic Laboratory purchased, and ACFI installed, a total of ten 1000-watt quartz iodine lamps in the Upper Bay area of the hot cells at R-MAD to facilitate better photographic services during post-mortem of NRX-A3.

SNPO-C approved the use of an existing trailer for additional space plus the equipment to provide a better NTO Technical Photographic Laboratory. Upon completion of this additional space, NTO Photographic Laboratory will be in a position to reproduce, in small quantities, color corrected photographic prints.

A system for photographing test articles at Test Cell "A" from a safe distance is being worked on. Plans are being made to introduce this for NRX/EST operations. Equipment for this operation is being purchased.

7.4 ETS OPERATIONS

7.4.1 STEAM GENERATOR TEST

A water-flow test was conducted to determine the plenum cooling jacket pressure drop. Functional tests were also performed on the steam generator pressure switches, and adjustments made where required.

Eighteen Steam Generator tests, per EP-I, have been satisfactorily conducted, including the following individual "Idel Tests" on each of three modules: two 10-second runs, two 180-second runs, and two 1020-second runs.

Six of the seven EP-II Steam Generator tests were completed (see Figure 80) with satisfactory results. Four additional tests were added in accordance with the Test Specification, Supplement No. 5.

Post-test inspection of Module S/N 0016 of the steam generator revealed one of the water fingers to be broken off and missing, but there were no damages nor abnormalities within the plenum. The broken finger was replaced with one from the spare module.

Work requests have been issued to the Support Services Contractor for fabrication of an extension of Flare Stack FS-5003, and the procurement of a flame arrestor. These two items wil alleviate scorching of the fire protection electrical-control system on top of the Test Stand under adverse wind conditions and will economize on the nitrogen purge in the stack.

During leak check on Injector S/N 0018 preparatory to completion of EP-II, a leak was noted at the injector-to-combustion chamber interface. Further examination, after disassembly, revealed visible evidence of hot-gas leakage at the injector-to-chamber seal. Injectors S/N's 0016, 0017, 0018, and 0019 (spare), were disassembled for inspection and the following was noted:

S/N 0016 - Cracks plainly visible around the periphery of the injector face and negligible crack noted in injector insert weld.

S/N 0017 - No visible damage.

S/N 0018 - No visible damage, except for incompleted weld at injector face cooling spud.

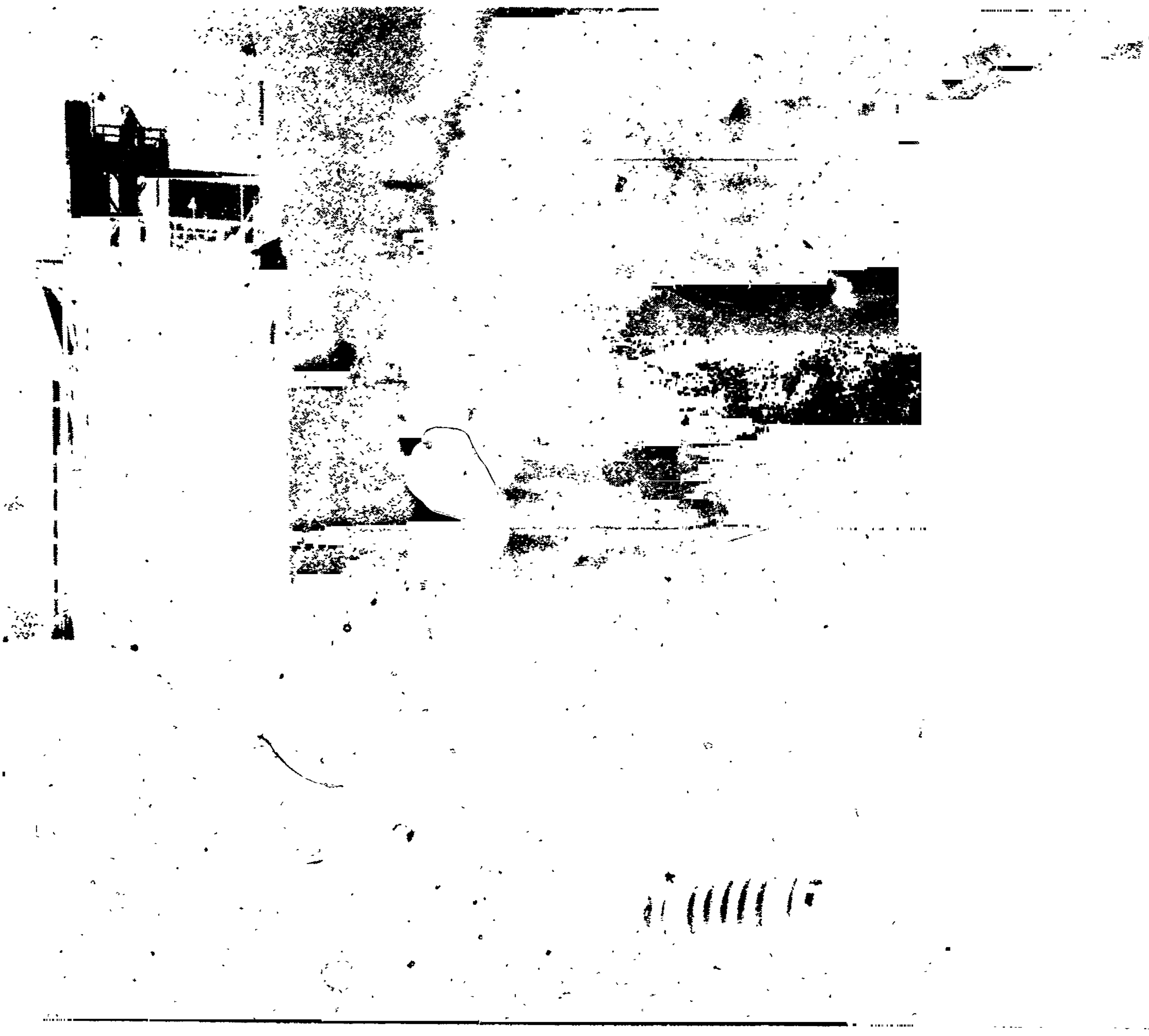


Figure 80

ETS-1 Steam Generator Testing

Medium Power Run, EP-II

S/N 0019 - Burned out second stage combustion chamber and bulging of the main chamber inner liner in a number of areas. Also, negligible crack noted in injector insert weld.

Various system modifications were performed, such as:

Installation of an emergency manual-operated vent valve in the propane system;

Fabrication and installation of gauge/valve panel for the LO_2 Storage Vessel Dewar, V-2801, to provide a consolidation of existing pressure gauges and valves which are presently located throughout the system;

Rerouting of the Main Steam Generator LOX Vent Line to a more favorable location;

Various modifications to the temporary Instrumentation and Control System to make it compatible with the test program requirements.

After approval of procedure NTO-I-0035 for the ETS-1 Process Water System Test Program by SNPO-C, Process Water System testing was initiated on the redesigned water system. Data are being analyzed and a report will be prepared.

Modifications were initiated to the appropriate console to make it compatible with the Thiokol Steam Generator Control System and the facility.

The cold checkout panel for the Steam Generator permanent I&C System was designed and fabricated. The necessary wiring tabulation for the transfer of the Steam Generator cabling from the transducer boxes to the blast wall terminal boxes utilized in the permanent I&C System was prepared.

The Communication System used for the Steam Generator Test Program was installed and checked out.

7.4.3 INTERFACE SYSTEM INSTALLATION AND CHECKOUT

Fabrication was completed on the manifold for the modification of the tank pressurization lines to include a first-stage pressure regulator upstream of the run-tank-pressurization valve, JC-PCV-16[illegible].

Drawings for the modification of Line 9-GH-8" were prepared to permit test verification of the theoretical flow calculations of the GH_2 system in support of the NERVA Exhaust System Duct Test.

Specifications were prepared and vendor submittals were reviewed for a LN_2 vaporizer.

Permission has been requested of SNPO-C to purchase a high pressure LH_2 vaporizer to replace the existing low pressure unit and the mechanical compressor system at ETS-1.

7.4.5 FACILITY SYSTEMS CHECKOUT AND ACTIVATION

A. GASEOUS SYSTEM ACTIVATION, OPERATION AND MAINTENANCE

Modification was completed on 17 each s/4" Security "RSV" Valves incorporating teflon back-up rings on the actuation piston. To date, no evidence has been observed of leakage past the actuation piston "O" rings.

A satisfactory proof-test was completed on the high-pressure gas vessel, V-3205, with GN_2 at 3750 psig to permit subsequent operation at a 2500-psig working pressure. The vessel has been recharged with gaseous helium in support of the cryogenic systems checkouts.

The fabrication of a pressure gauge/valve panel was initiated for the high-pressure gas system in Area "32". The purpose of the panel is to consolidate system gauges and valves to enhance operation and facilitate maintenance.

A satisfactory operational check of the GHe and GH_2 compressors was completed. All leaks were corrected, with exception of the unloader valves, which will be corrected during a system-down period.

B. CRYOGENIC SYSTEMS CHECKOUT (PHASE III)

Work continued for activating the LH_2 Storage Dewar, V-3801, and associated plumbing. A leak was located in the transfer line jacket within the annular space of V-3801. A leak-rate test was performed and witnessed by a CB&I representative. The data obtained from the test indicated that the leak was in excess of the normally allowable limits. Repair of the questionable area has been performed by CB&I. Effectiveness of the repair work was under review.

A satisfactory vacuum hold test on the annular space and an ambient leak test of the inner vessel of the high-pressure LH_2 run vessel, V-5002, was completed.

A vacuum hold test was initiated on the annular space of the low-pressure LH_2 run vessel, V-5001, for leakage evaluation. Fabrication of a 4" dump line system and a liquid-level indicator system for V-5001 was initiated to facilitate subsequent LH_2 flushing operations during Activation Checkout tests.

A satisfactory vacuum hold test was conducted on the annular space of LN_2 storage dewar, V-3601. Procedure NTO-I-0029 for the LN_2 system checkout has been approved by SNPO-C.

C. INSTRUMENTATION AND CONTROL ACTIVITIES

Engineering support was provided during ETS-1 Facility Systems checkout, operation and maintenance operations.

Rerouting cables continued for solenoid valve boxes, SVB-6 and -7, for incorporation into SVB-10 and -11 in support of the Interface System installation.

Fire Protection Zones were activated, including the removal of the control from the Master Control Panel to the Steam Generator Control Van. Checkout tests, conducted by the Automatic Sprinkler Company, were monitored. Engineering and technical supervision was performed to determine which heat sensing devices were activating the deluge system in the Test Stand zone.

Specifications were prepared for the Data Processor Program for Data Patching. The diagnostics programs for the digital-data checkout tests, Data System final-acceptance tests, and the calibration checks were completed. Work is continuing on the channelization-check program and the "Road Map" Program. Subroutines for certain of the programs have been completed with continuing effort on remaining subroutines.

Design modification work was initiated to incorporate the Fire Protection System into the Safety System, and a proposal was completed to make the fire protection and CO_2 packages compatible with the Safety System.

Necessary coordination was performed to resolve the Measurement Requirement List for the XE Cold Flow tests and the Facility Checkout. Channel-engineering input data were developed for the ETS-1 shields and exhaust duct; and Channel-Request forms were initiated for incorporation of functional assignments for channel engineering.

Preparation of the I&C System Operations and Maintenance Manuals was initiated.

Spare Parts requirements and necessary procurement documents were defined for the I&C System.

Functional requirements for the ETS-1 Data Link were prepared, in conjunction with EG&G, and presented at a meeting of representatives of SNPO-W, SNPO-N, SNPO-C, LASL and other NRDS organizations.

7.5.2 E-MAD ACTIVATION

A. MANAGEMENT

Efforts were provided for planning, liaison, integration, and coordination of all E-MAD related contract activities and for directing, review, and scheduling of effort to support the acceptance, operation, maintenance and activation of the E-MAD Complex.

Planning and scheduling of efforts was provided to support the acceptance, operation, maintenance, and activation of the E-MAD Complex.

Planning and scheduling activities were performed for the E-MAD Complex on such items as the facility equipment and system installations, acceptance tests, activation documentation and performance of Shielding Integrity Check Tests. An updated activation network was completed and issued during April 1965.

Continuous monitoring was maintained during the disassembly of the NRX-A3 reactor at the R-MAD Facility with specific interest on application of the operation and facility locations of the disassembly of the components to the E-MAD Facility.

B. E-MAD ACTIVATION

Activation status tests and activation status reports were prepared for the Counting Room (Room 107), the Health Physics Office (Room 108), the Core Assembly and Storage Area (Room 112), the Air Lock (Room 113), the Engine Receiving and Inspection Room (Room 114), the Main Cold Assembly Area (Room 115), the Vestibule (Room 116), the WT-1 Turntable and the V-2 Crane.

C. EQUIPMENT INSTALLATION

The Wall Mounted Handling System and Rectilinear Manipulator were received, installed, and acceptance tests were initiated during this report period.

The Overhead Positioning System was received and installation is complete. Acceptance tests are scheduled to begin on 1 July 1965.

The Floor Mounted Handling System was installed and acceptance tests were initiated.

Nine pairs of Master Slave Manipulators with roller sleeve assemblies and two shielding plugs were installed in the master slave manipulator holes of the post-operative cells. Acceptance testing of a total of ten pairs of eight foot pivot to pivot Master Slave Manipulators has been completed with NTO operational support.

The Receiving Dolly (Provisioning List No. 5226) was received and checked out after damage incurred during the shipment was repaired. The RF transceivers from the Manned Control Car and the Locomotive were received and checked out during a preliminary check of the RF communication along the railroad track.

D. SHIELDING INTEGRITY TESTS

The final report for Phase I of the Shielding Integrity Check test has been completed for final review. Phase I is comprised of the Main Hot Bay (Room 122) and the Crane Maintenance Balcony (Room 306).

The procedures for Phase II of the Shielding Integrity Check test are complete and have been approved, but Phase II of the SIC test was postponed due to delays in the installation of the Master Slave Manipulators. All wall and ceiling grid work is complete. Phase II comprises the walls between the Post-Operative Cells and the galleries and the ceilings of the cells.

Phase III of the SIC test was completed. Two areas associated with blocked-up pass-throughs in Rooms 127 and 130 were accomplished as an addendum. One violation required further work after confirmation. The second repair has been completed but has not yet been re-confirmed. The Phase III Shielding Integrity Check test final report is complete, with the exception of the confirmation of shielding integrity of the deficient areas, which will be obtained during the conduct of the Phase II Shielding Integrity Check test. Phase III comprises the Hot Hold and Transfer Tunnel (Room 128) and the Cell Service Area (Room 173).

Site Support Services RAD/SAFE Monitors were used during the Phase III SIC test and were directed by the SIC Test Director and NTO Health and Safety.

E. DOCUMENTATION

An SOP for Inspection and Testing of All Hoisting and Rigging Equipment was completed.

Preliminary heating, ventilation and air conditioning SOP's are being prepared for issue. Preliminary operational development procedures for the Floor Mounted Handling System were prepared for review.

Approximately 50% of the requisitions processed for the E-MAD Machine Shop tools, stocks, etc. were filled during this report period.

F. FACILITY MODIFICATIONS

The WT-1 Turntable deck-plate was modified to eliminate warpage incurred as a result of heavy loads passing over it.

An experimental intercell was erected between Cells 166 and 171.

The OPS haunches were modified to accommodate the installation of the busrail support brackets.

Facility gas, electrical and public address system piping was modified in the Cell Service Area to provide proper interfacing with the rectilinear manipulator.

7.8 TRAINING

These chapters of the ETS-1 Instrumentation and Controls Course were completed:

- NERVA Program Orientation
- Description of ETS-1 Complex
- Instrumentation Fundamentals
- Introduction to Facility Control System
- Facility Control Systems
- Electrical Power System
- Television System
- Introduction to Data Acquisition System
- Analog Recording System
- Events Recording System
- Digital Data System
- Introduction to Test Stand Control System
- Process Systems Controls

The following chapters are in process of completion:

- General Capabilities of I & C System
- Communications System
- Channel Engineering
- Safety Systems
- Signal Conditioning System
- Timing System
- Engine Control System

The training schedule summaries for E-MAD Operations for (1) Factory Training and (2) On-Site Training are shown in Tables 8 and 9, respectively.

These E-MAD training activities were completed during this quarter

Mouth-to-Mouth Resuscitation and Closed Chest Heart Message (Several one-hour sessions; 166 trainees including ETS-1).

WMHS factory training at Pittsfield, Mass. (4 trainees).

Fire Protection at E-MAD, for E-MAD Fire Wardens. (Four 2-hour sessions completed- 7 trainees).

Rigging for "cold" operations. (two 2-hour sessions; 9 trainees)

E-MAD Nuclear Orientation Course (now in progress; three 2-hour sessions completed to date; 11 trainees)

The following one-week, full-time courses were completed:

Control Data Corporation Computer Fundamentals

CDC 3200 Computer Programming

CDC 3200 Computer SCOPE-COMPASS Programming

Seven additional NRX test operators were qualified on April 2, 1965.